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1. INTRODUCTION

The subject of the study is the investigation of Filtralite filter media potential in ground water treatment process. The research site was located at an operational DWTP. The plant supplies potable water for 30.000 citizens. The research setup has been running since Dec. 2018, till Jun. 2019. The setup consisted of three filtration columns. The main focus of the study was to test for the removal of iron, manganese and ammonium ion at various filtration rates.

The foundation for this study is:

- Contract between Leca Polska sp. z o.o. and the NENTECH S.C. Karol Szambelańczyk Łukasz Weber
- Detailed scope of the research included in the NENTECH S.C. Karol Szambelańczyk Łukasz Weber offer
- Data collected during the research, supported with knowledge and experience of the research team.

The report form the study is divided into four main parts:

- Theoretical background of the treatment process focused on Fe, Mn and NH4 removal
- Scope of the research, used methods and techniques, description of the research equipment
- Results and observations
- Final conclusions and specific designing guide for the process

The study includes comments and answers to issues and questions reported during the research work and preparation of this report.

2. THEORETICAL BACKROUND

Ground water is the dominant supply source for drinking water treatment in Poland.
The most commonly occurring contaminants are:

- Iron,
- Manganese,
- Ammonium ion.

Among different water treatment, those which focus on contaminants mentioned above are vital.
Majority of DWTPs in Poland runs a process based on one-stage or two-stage filtration, preceded with raw water aeration.
The most commonly used filter media materials are:

- Quartz sand,
- Chalcedony,
- Anthracite.

A special type of filter media is so called 'catalytic filter media', which grants an instantaneous effect of Mn removal, with no working-in needed. The popular brands of those are 'active mass G1', 'Multimann', '3M', 'Pyrolusite', 'Defemann'. Various catalytic media have different content of manganese oxide. MnO_2 incorporated in the media grains works as the active site for the catalytic oxidation of Mn^{2+}, hence the name of this filter media type.
More detailed basis of each contaminant removal is presented in the following chapters.

2.1. Iron removal

Dissolved form of mineral iron (Fe^{2+}) is very abundant in the ground water. Its' content in the surface water is usually low, yet most likely complexed by organic compounds.
In Poland and in many other European countries the limit for Fe content in treated water is **200 µg/L.**
Water with higher content of iron is highly problematic from the perspective of technology and consumers. Potable water with exceeded Fe content has an unpleasant smell and taste.
Iron precipitates can deposit in the piping grid and significantly increase power consumption for pumping. Also, some undesired bacteria are prone to growing in iron deposits.
The treatment process needs to be designed with care, when iron concentration in raw water is higher than 1 mg/L. The challenges, that are likely to appear are: a need of frequent backwashing, regular clogging, Mn removal inhibition – especially if Fe is not removed at the depth where Mn removal is expected.
Most ground water yield iron in the form of soluble Fe^{2+} ion. The treatment process is based on oxidation to insoluble Fe^{3+} form and filtering the resulting precipitate. Air oxygen is a sufficient oxidizing agent for the process. Different oxidizing agents (permanganate, hypochlorite) are also reported to be effective (higher reaction rates), but more expensive in dosing. The effectiveness of oxygen is dependent upon the contact time between the raw water and the supplied air.

The mineral iron removal process in the filter can be split into two mechanisms:

- Physical filtration of already precipitated Fe_2O_3. It occurs in the most top layers of the media (0,1÷ 0,5 m of fine media),

- Chemical oxidation of remaining Fe^{2+} at the surface of media enriched with Fe_2O_3 deposits. This mechanism requires oxygen in the water being filtered. The presence of iron(III) oxides enhance this process, because it serves as the catalyst for iron(II) oxidation.

The later mechanism is observed into deeper layers of the media, because the incoming soluble iron ion is capable of penetrating deeper into the filter than a solid particle, before it undergoes oxidation (precipitation).
This results in:

- Slower clogging,
- Increased working volume (bigger capacity is used for iron precipitate filtration),
- Higher risk of iron precipitate passing the filter (only when filtration rate is changed rapidly).

When designing a one-stage filtration process it is essential to assure iron removal layer as short from the top of the filter media as possible. The remaining media depth from the bottom must be iron-free in order to remove manganese, regardless the media type.
There are many reasons why a one-stage filtration is superior to two-stage filtration. However the most obvious one is, that all the contaminants can be removed in a single step. For multi stage filtration the contaminant, that is meant to be removed at the last stage (ie. Mn) will have to pass through the nozzles, piping and pumps at previous stage filters. It has been reported, that from such a partially treated water some deposits of Mn are observed in the nozzles of stage 1 of 2 filter.

2.2. Manganese removal

The limit for Mn concentration in treated water is 50 μg/L. The effect of excessive Mn content is an unpleasant smell and taste, but also staining.
Manganese similarly as Iron can deposit in the piping grid and significantly increase power consumption for pumping. The undesired bacteria growth is even more problematic in case of Manganese.
Removing Manganese from raw water is more difficult than removing Iron. Also Manganese occurs in a dissolved (Mn^{2+}) form in ground water. The difficulty with oxidizing Manganese to insoluble Mn(IV) lies in the fact, that mere air oxygen is not sufficiently strong oxidizing agent for Mn, at typical ground water pH.

Thus, for water treatment processes oriented toward Mn removal, following techniques are used:

- Strong oxidizing agents addition. Potassium permanganate and hypochlorite are the most common, but need to be constantly dosed,
- Oxidation with oxygen at raised pH (higher than 9),
- Catalytic filter media. The product of the oxidation reaction (MnO_2) is at the same time a catalyst for the reaction.

The third method is the most commonly used in DWTPs in Poland.
There are two ways to achieve catalytic oxidation of Mn with the filtering media.

- Many different media can be worked-in toward catalytic Mn oxidation, by natural bioprocess. The Manganese oxide is armoring the media grains forming a catalytic layer,
- Manganese ore can be formed into a filter media. This material is rich in MnO_2, so the catalytic effect is observed since implementation.

The vast majority of DWTPs in Poland chose the catalytic media over media, that require work-in procedure. The time and effort needed for the work-in makes this method occasionally chosen nowadays.
In the former approach the grains of the original material are armored with MnO_2 precipitate, that formed over time from incoming Mn(II). In the later the whole media grains constitute of mostly MnO_2 only.
Regardless the approach, the final effect is similar - the outer layer of the grains in the bottom layer of the filter is covered with MnO_2.
The MnO_2 presence at the surface of the media grains is essential for the catalytic reaction.
When aerated raw water flows through the media, the dissolved Mn^{2+} adsorbs to manganese oxides present at the surface of media grains. The adsorbed Mn^{2+} is oxidized by means of reduction of the MnO_2 from the media surface, resulting in two equivalent Mn(III) immobilized at the media surface. Both Mn(III) can are further oxidized to final Mn(IV) form of MnO_2 with oxygen from the aerated water. In the end the original Mn atom is restored to its' initial oxidation state, hence served as a catalyst. The Mn^{2+} ion, that undergone oxidation is in the insoluble MnO_2 precipitate form and should be removed from the filter by backwashing. In this manganese removal technique the media surface tends to complete saturation with MnO_2 and layer growth. The growth must be compensated with backwashing. (A similarity can be pointed to bioprocesses, in which the media surface is covered with biofilm, and excessive growth of biomass is removed during backwashing).
This method of Mn removal will fail, unless Fe is thoroughly removed. Manganese oxidation is always observed in the bottom layers of the filter (this includes even the surface of the supporting layer if present). It is established, that Fe^{2+} is adsorbing more easily on the surface of catalytic layer of MnO_2, than Mn^{2+} ions. This leads to inhibition of catalyst sites. This phenomenon is difficult to reverse, which makes restoring the media's desired property problematic. The effective removal of iron in the top layers of the media is essential for the manganese removal process.

The necessary conditions for this technique are:

- Sufficient aeration of raw water (oxygen is need for the second step of oxidation mechanism),
- Effective removal of iron, prior to manganese removal,
- Development of the catalytic layer in the natural work-in method,
- Elimination of disinfectants in the natural work-in method, because the work-in is a bioprocess,
- Ensuring optimal pH. (Higher than 7,0).

The alternative method of strong oxidizing agent application (ex. Breakpoint chlorination) is not dependent on above conditions, but extremely more expensive in operation. Besides, this methods makes biological removal of ammonium ion impossible.

Several research team established independently, that the natural work-in for manganese removal (catalytic layer deposition) is a bioprocess. Certain microorganisms are able to metabolize Mn^{2+}, storing the oxidation products (MnO_2) in body cells. The introduction of MnO_2 from bioprocess at the media surface is a start for the chemical (catalytic) development of the MnO_2 layer.
In the most desired model both chemical and biological removal of manganese take place in the filter media. However, initial only bioprocess takes place and initiate the work-in for non-catalytic media.

Both field experience and university research confirm, that the work-in of catalytic layer is biological in nature.
In the study conducted by D.Sc Rafal Bray at Gdansk University of Technology, the work-in of quartz sand has been investigated. By using manganese containing water with and without disinfectant, it has been established, that the work-in occurred in the media only in the absence of the disinfectant.
Also our own experience confirms the importance of bacteria in work-in process. In 2008 we carried out an experiment, that utilized suspension-free backwash water from existing and operational plant. This bacteria and manganese rich water was directed to filters with brand new filter media. By means of this method it was possible to achieve complete work-in 3 times faster, than by regular method.

The natural work-in time is sensitive to many factors, but especially to Mn concentration in the raw water. For concentration higher than 0,5 mg/L the work-in time usually is less than 3 months. Below inlet concentration of 0,1 mg/L the natural work-in time can exceed 12 months.
Another important factor is the filtration rate. It has been confirmed, that low filtration rate favors the work-in. The attempts to lower the rate of filtration below 1,0 m/h proved the effectiveness of the approach. The full scale experiment allowed to achieve natural work-in in less than 3 weeks. This is a practical hint for working-in the filter media. Namely, perform the work-in at low rate, than increase the rate to the expected working filtration rate for the filter.
In discussed technique the bioprocess is important for the work-in and enhancing the chemical (catalytic) process. Every bioprocess is vulnerable to disinfectants like strong oxidation agents used in water treatment (permanganate, hypochlorite). In some case addition of this chemicals prior to filtration may result in deterioration of already developed process.
Precautions mentioned above apply also to any bioprocess, like ammonium ion removal.

2.3. Ammonium ion removal

The limit for NH^{4+} concentration in treated water is **50 µg/L**. The origin of ammonia in ground water can be natural or a result of the human activity. A sudden occurrence of the ammonium ion in ground water is most likely a result of an uncontrolled wastewater discharge. It is an alarming situation, because the pollution with ammonia is usually accompanied with biological pollution.

There are three main methods of ammonia removal from water:

- Degassing,
- Biological nitrification,
- Ion exchange techniques.

The most useful and versatile method is biological nitrification. It is also fairly easy to run nitrification altogether with Fe and Mn removal, since these are all aerobic processes.
However, certain conditions must be met for successful biofiltration.

The equilibrium of ammonium ion vs. ammonia is directly dependent upon the pH.

$$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$$

The higher the pH, the more gaseous ammonia. Gaseous ammonia is easily removed by open air aeration.
Almost complete removal of ammonia is possible for degassing setups if a maximal contact area is achieved by an intense sprinkling in a countercurrent air stream. The example of such equipment are aeration cascades and sprinkled beds.
However, this method is not applicable for removing ammonia in the dissolved NH^{4+} form.
This is the case for the most common pH range for ground water. On the other hand, it is possible to perform degassing anyway, by raising the pH. Unfortunately it is a costly method, and the pH needs to be lowered afterwards by addition of another acidifying agent.

Therefore, biological nitrification is the best method of choice, especially for ammonium concentration < 1,0 mg/L.
The mechanism and conditions for biological nitrification are described below. Ammonium ion oxidation is a two-step process.

<u>In stage I Nitromonas bacteria are involved:</u>

$$15\ CO_2 + 13\ NH_4^+ \rightarrow 10\ NO_2^- + 3\ C_5H_7O_2N + 23\ H^+ + 4\ H_2O + 270\ kJ/mol$$

<u>Nitrobacter bacteria are responsible for stage II:</u>

$$5\ CO_2 + NH_4^+ + 10\ NO_2^- + 2\ H_2O \rightarrow 10\ NO_3^- + C_5H_7O_2N + 80\ kJ/mol$$

$C_5H_7O_2N$ – simplified formula of biomass cell (stoichiometric biomass growth).

The effective nitrification requires prolonged contact time of biomass with water containing ammonium ion. The growth of biomass is effective upon presence of substrates for metabolism - oxygen, ammonium, also phosphates and right alkalinity.
It is worth noting, that nitrification does not remove nitrogen compounds from treated water, but just changes it's form. Nitrates are product of nitrification and are also a contaminant, which concentration must not exceed a regulation limit. In seldom cases very effective nitrification process can lead to undesired increase of nitrate concentration. Nitrate removal requires alternations in the TP technology system. This topic is not covered in this study.

The porosity of the filter media favors the development of bioprocesses.
Removal of the ammonium ion should be monitored by the DWTP operation team and the lab. (especially for nitrate and nitrite concentration in treated water). The removal of ammonia and the absence of nitrites (NO^{2-}) in the treated water means, that the nitrification process is running properly.

The conditions required for the nitrification process are:

- Raw water aeration (4,5 mg/L per every 1 mg/L of ammonium ion),
- Temperature higher than 4 °C for bioactivity,
- Preferable pH 7,0-7,5,
- No disinfectants added prior to filtration.

The above conditions are necessary for correct bioprocess for ammonium ion removal.

2.4. The overall treatment process for Fe, Mn, NH^{4+}

A simultaneous removal of iron, manganese and ammonium ion is possible in a single stage filtration. Plenty of DWTPs in Poland use a one-stage filtration for ground water treatment.

The characteristics of such setup is as follows:

- The media depth must be large enough to accommodate all functional layers (where particular contaminants are removed). The layer meant to remove iron is often the highest.
- The raw water must be aerated prior to filtration. The extent of aeration is connected to stoichiometric calculation of oxygen demand to oxidize all the contaminants.
- The order of layers (from the top) in the filter is:
  - Upper iron removal layer (physical filtration),
  - Lower iron removal layer (oxidation and physical filtration),
  - Ammonium layer (bioprocess partially overlapping with iron removal layer),
  - Manganese removal layer (always at the most bottom of the media).
- The total media depth is higher for:
  - Higher filtration rates,
  - Application of coarse grain material in the top of the filter,
  - High iron content in raw water,
  - Low extent of iron oxidation in aeration step.

For properly designed filtration setups it is possible to run a complete treatment process I one-stage filtration.
As already mentioned before, one-stage filtration is far advantageous in comparison to two-stage filtration. Unfortunately, in last two decades there have been lots of two-stage filtration TP built in Poland. During that period many weak point of this setup have been revealed and identified. The most relevant is the contact of stage one nozzles with only partially treated water still contaminated with manganese. Two-stage filtration utilize more pieces of equipment and requires more backwash water, that is why it is always more expensive in terms of CAPEX and OPEX.

Therefore, it is most reasonable to choose one-stage filtration, unless there is a reasonable obstacle (ex. Too little height at the existing plant building).

3. OBJECT OF RESEARCH

3.1. Filtralite Pure HC 0,8-1,6

The research study has been done with Filtralite Pure HC 0,8-1,6 filter media manufactured by Leca. This material was preselected from wide range of Leca Filtralite products, as the best choice for ground water treatment (removal of Fe, Mn, NH^{4+}). Filtralite is a high quality filtering material made of expanded clay aggregates (HC is a crushed, high density type). The main advantages according to the manufacturers are: lower initial head loss, less head loss buildup in filter cycle, high capacity for contaminants, and less backwash water consumption (Pic. 1, 2).

Pic. 1 Filtralite Pure HC 0,8-1,6 (close up)

Pic. 2 Filtralite Pure HC 0,8-1,6

The material properties of Filtralite Pure HC 0,8-1,6:

- Type of the material: expanded clay,
- Appearance: Crushed particles, porous surface structure,
- Bulk density, dry, compressed: 850 kg/m^3,
- Particle density, apparent: 1700 kg/m^3,
- Particle size range: 0,8-1,6 mm.

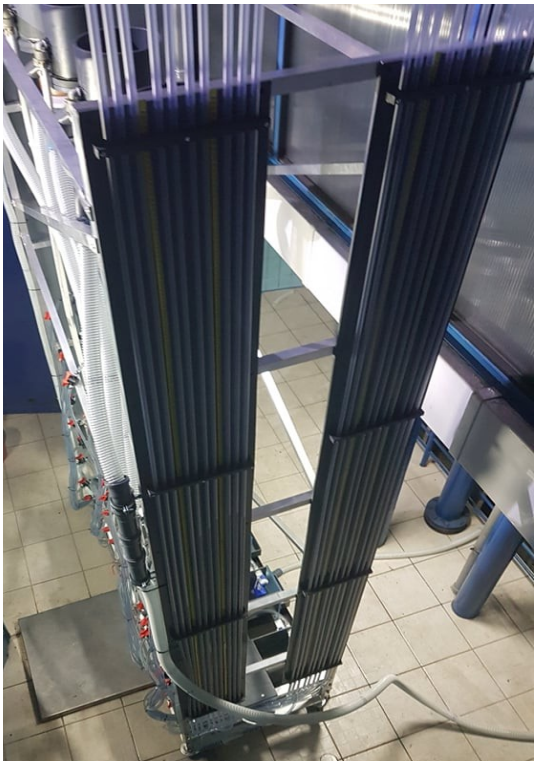
Chemical composition (approx values):

- SiO_2 – 63%,
- Al_2O_3 – 17%,
- Fe_2O_3– 7%,
- K_2O – 4%,
- CaO - 2%,
- Na_2O – 2%.

3.2. Research equipment and setup

The research site was located at an operational DWTP. The plant supplies potable water for 30.000 citizens.
The research equipment consists of 3 plexiglass filtration columns mounted in alumina casing (Pic. 3). The columns are 0,09 m in diameter each. There are 10 side nozzles at every 20 cm of column height. The nozzles are used for sampling and piezometric head loss measurements at consecutive depths of the media (Pic. 4, 5). The filtration rate is controlled by the float valve at the outlet of the column. The adjusted filtration rates are 6, 9 and 12 m/h for each column respectively (Pic. 6). To assure a constant freeboard and water pressure above the media the excess of the inlet water is gravitationally directed to the overflow at the top of the columns.
The columns were filled with 1,7 m high Filtralite Pure HC 0,8-1,6 media on 0,2 m high supporting layers. The freeboard was 1,1 m in every column.
The described setup is analogous in terms of height to full scale filters operating in the DWTP.






Pic. 3,4,5 and 6 Research installation

3.3. Raw water parameters

The raw water intake is a water from multiple well (100 – 150 m deep). The ground water parameters vary for every of the 15 wells. The overall intake water contains excessive concentration of Fe, Mn and NH^{4+}. The average raw water parameters are presented in the table below.

Tab. 1 The average intake water parameter during the research

Parameter	**Unit**	**Value**
Color	[mgPt/L]	155
Turbidity	[NTU]	5,38
pH	[-]	7,64
Iron (tot.)	[mgFe/L]	1,00
Manganese	[mgMn/L]	0,32
Ammonium ion	[mgNH^{4+}/L]	0,67

The raw water is aerated in the aeration cascades and directed to the reaction tanks, where initial oxidation of iron and its' sedimentation takes place. The retention time is 20 minutes. Then the water is pumped into the full scale filters. The same water is used as a feed for the research equipment.

The dissolved oxygen level is 9,43 mgO_2/L on average (min. 8,86 mgO_2/L, max. 10,15 mgO_2/L).

3.4. The scope of the research

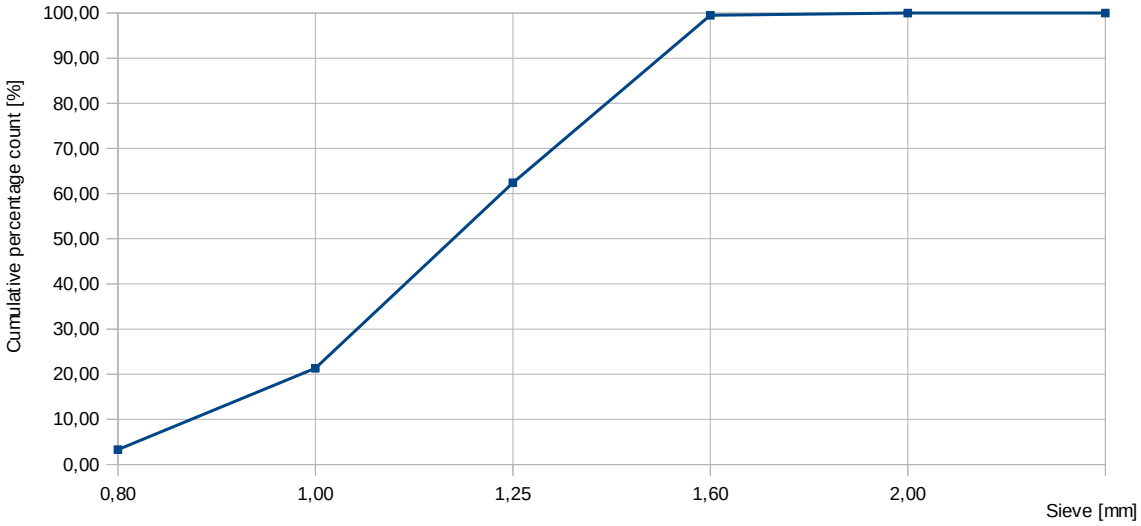
At first the samples of the media have been tested for the material properties:

- Grain size analysis (Tab.2, Fig.1),
- Bulk density measurements.

Tab. 2 Grain size mass percentage for Filtralite Pure HC 0,8-1,6

Sieve	Mass of grains[g]			Average [g]	Cumulative percentage count [%]
mm	Series I	Series II	Series III		
Undergrain	3,6	3,2	3,1	3,30	3,30
0,80	18,6	18,25	17,2	18,02	21,32
1,00	40,6	41,65	41	41,08	62,40
1,25	36,95	36,25	38,05	37,08	99,48
1,60	0,25	0,65	0,65	0,52	100,00
2,00	0	0	0	0,00	100,00
Sum	100	100	100	-	-

Fig. 1 Sieving curve for Filtralite Pure HC 0,8-1,6



The filtration routine assumed 7 days filter cycles. Following parameters have been monitored for every cycle:

- Iron concentration at inlet/outlet 5 times/week, and at consecutive depths 2 times/week,
- Ammonium ion concentration at inlet/outlet 5 times/week, and at consecutive depths 2 times/ week since work-in,
- Manganese concentration at inlet/outlet 5 times/week, and at consecutive depths 2 times/week since work-in,

- Head loss at consecutive depths 2 times/day,
- Color, turbidity, dissolved oxygen, pH at inlet/outlet every week.

In the end of every filter cycle, columns were backwashed according to following procedure:

- Backwashing with air only for 5 min. 15,0 L/sm^2,
- Backwashing with water only for 10 min. with various intensity 10-15 L/sm^2.

By analysis of the collected backwash data backwash expansion and effective backwash duration have been established.

4. RESULTS OF RESEARCH

The graphic depiction and analysis of Filtralite Pure HC 0,8-1,6 performance is presented in chapter 4. The results presentation is focused on:

- effectiveness of the treatment process for Fe, Mn and NH^{4+},
- determination of contaminants removal layers,
- estimation of mass capacity for iron oxides,
- head loss profile,
- backwash procedure optimization.

4.1. Iron, Manganese and Ammonium ion removal at the rate of 6 m/h filtration column

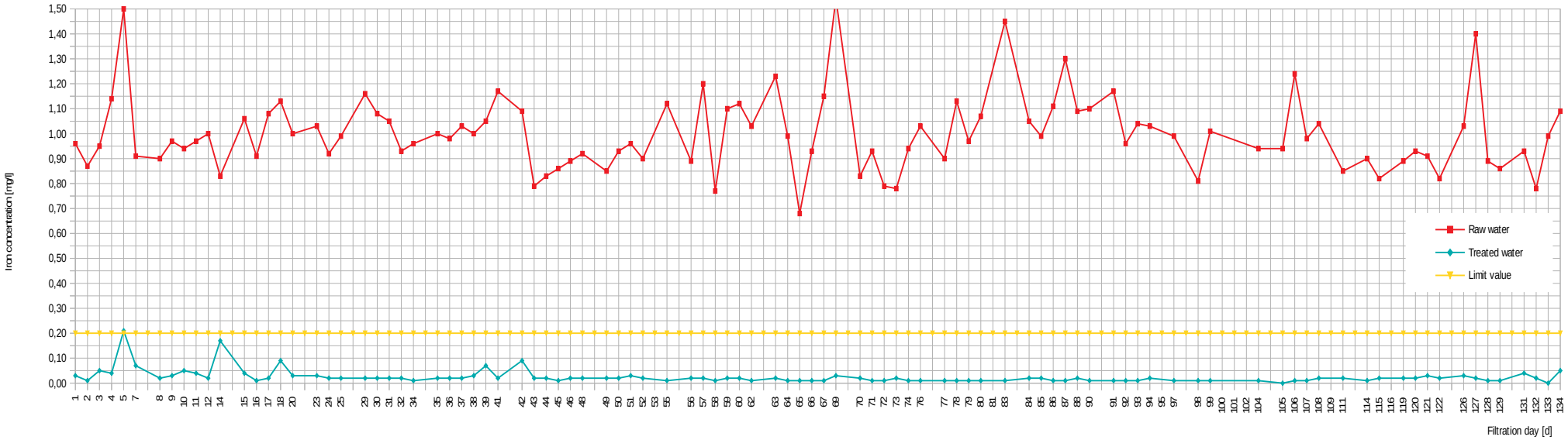
In this paragraph the outlet concentrations of Fe, Mn and NH^{4+} are given for the entire research period for the column operating at 6 m/h with Filtralite Pure HC 0,8-1,6 media. The concentration graphs include the raw water parameters and the regulation limit for treated water.

4.1.1 Iron removal

In order to determine the effect of treatment for iron removal, the concentration of iron has been monitored daily.

The following graph represents the concentration of iron for the column operating at 6 m/h.

Fig.2 The effect of treatment for iron removal for the entire research period at 6 m/h filtration rate

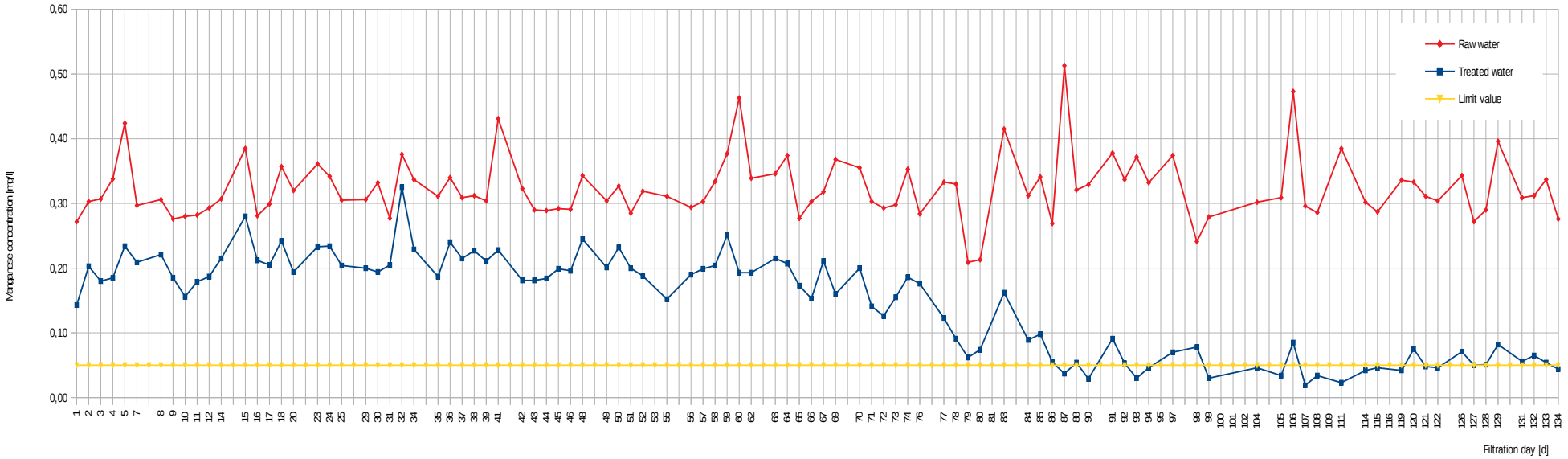


4.1.2 Manganese removal

In order to determine the effect of treatment for Manganese removal, the concentration of Mn has been monitored daily.

The following graph represents the concentration of manganese for the column operating at 6 m/h.

Fig.3 The effect of treatment for manganese removal for the entire research period at 6 m/h filtration rate

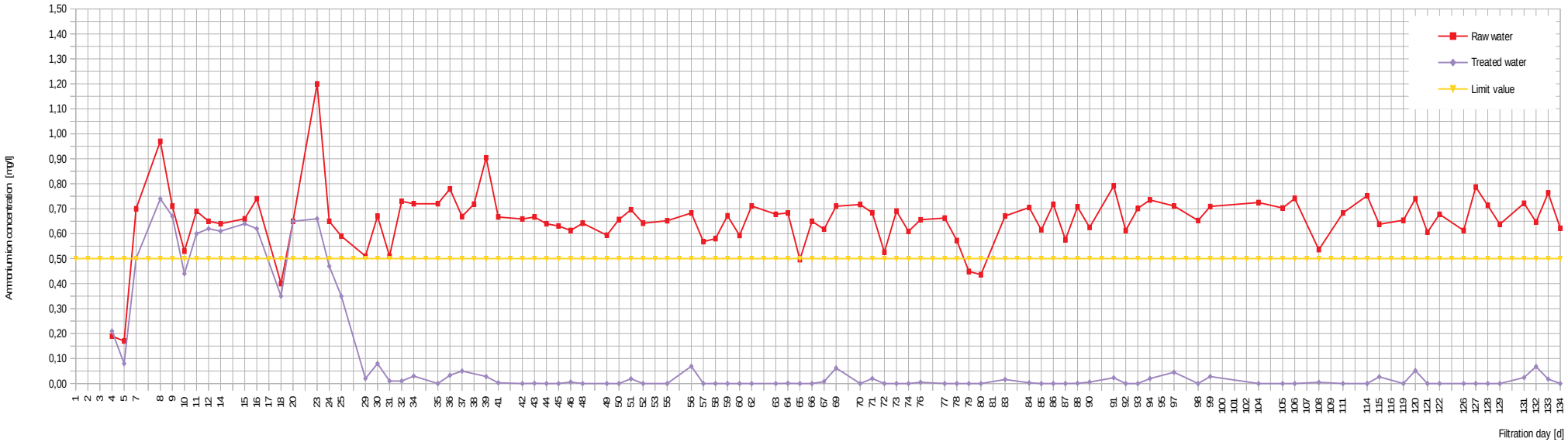


4.1.3 Ammonium ion removal

In order to determine the effect of treatment for Ammonium ion removal, the concentration of NH^{4+} has been monitored daily.

The following graph represents the concentration of ammonium ion for the column operating at 6 m/h.

Fig.4 The effect of treatment for ammonium ion removal for the entire research period at 6 m/h filtration rate



4.2. Iron, Manganese and Ammonium ion removal at the rate of 9 m/h filtration column

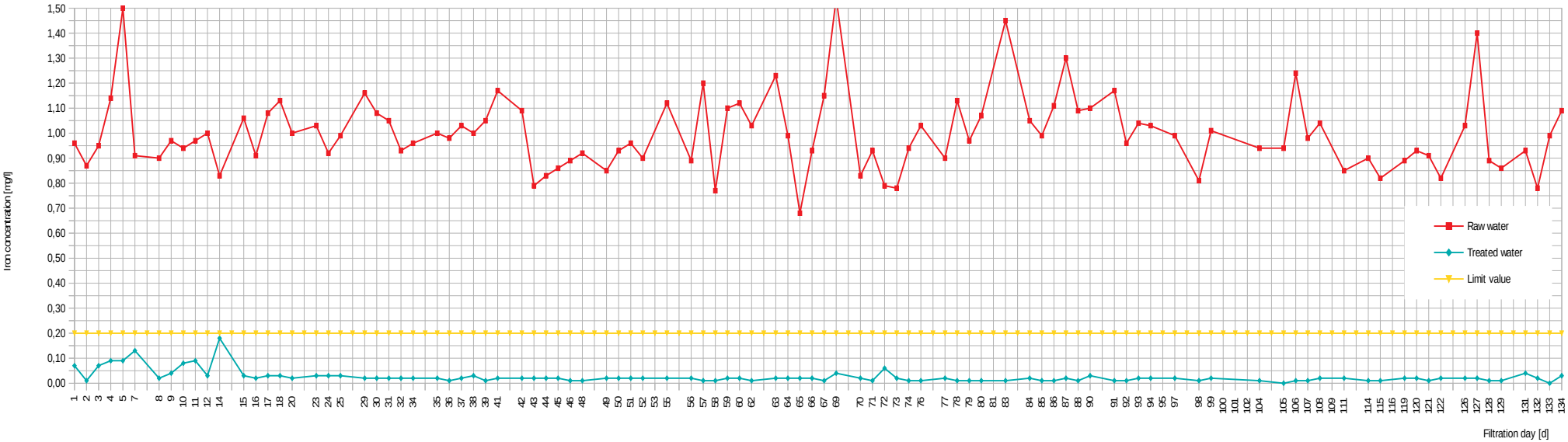
In this paragraph the outlet concentrations of Fe, Mn and NH^{4+} are given for the entire research period for the column operating at 9 m/h with Filtralite Pure HC 0,8-1,6 media. The concentration graphs include the raw water parameters and the regulation limit for treated water.

4.2.1 Iron removal

In order to determine the effect of treatment for iron removal, the concentration of Fe has been monitored daily.

The following graph represents the concentration of iron for the column operating at 9 m/h.

Fig.5 The effect of treatment for iron removal for the entire research period at 9 m/h filtration rate

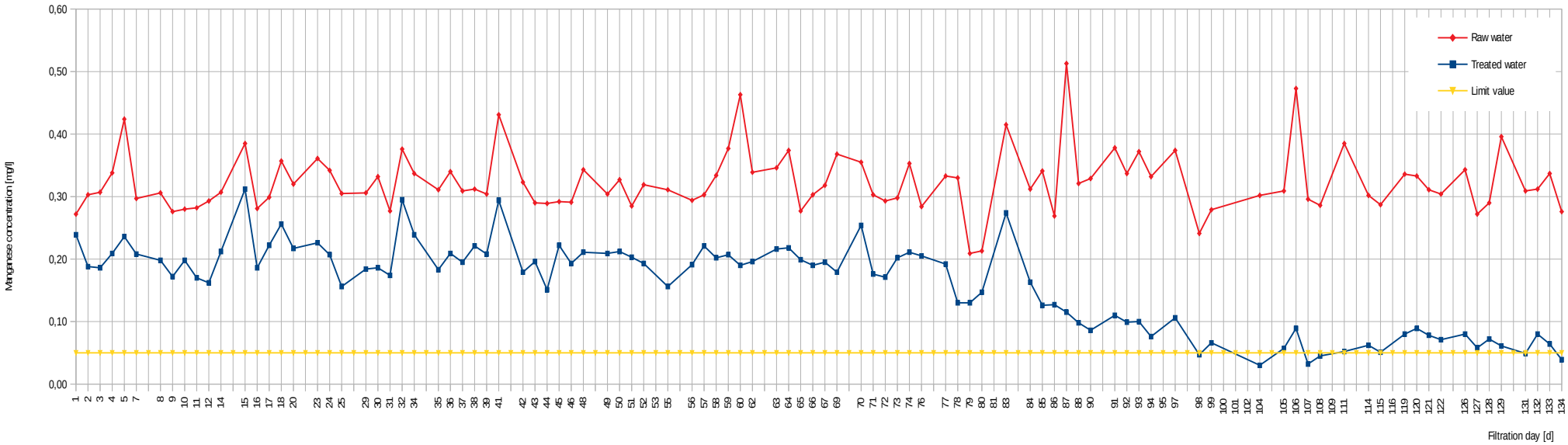


4.2.2 Manganese removal

In order to determine the effect of treatment for Manganese removal, the concentration of Mn has been monitored daily.

The following graph represents the concentration of manganese for the column operating at 9 m/h.

Fig. 6 The effect of treatment for manganese removal for the entire research period at 9 m/h filtration rate

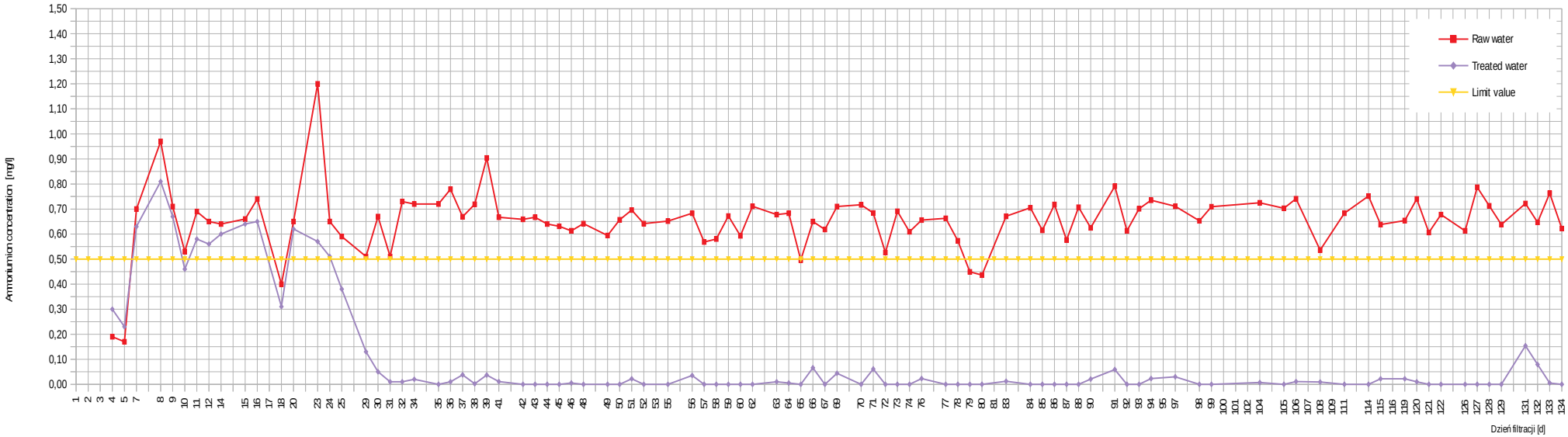


4.2.3 Ammonium ion removal

In order to determine the effect of treatment for Ammonium ion removal, the concentration of NH^{4+} has been monitored daily.

The following graph represents the concentration of ammonium ion for the column operating at 9 m/h.

Fig. 7. The effect of treatment for ammonium ion removal for the entire research period at 9 m/h filtration rate



4.3. Iron, Manganese and Ammonium ion removal at the rate of 12 m/h filtration column

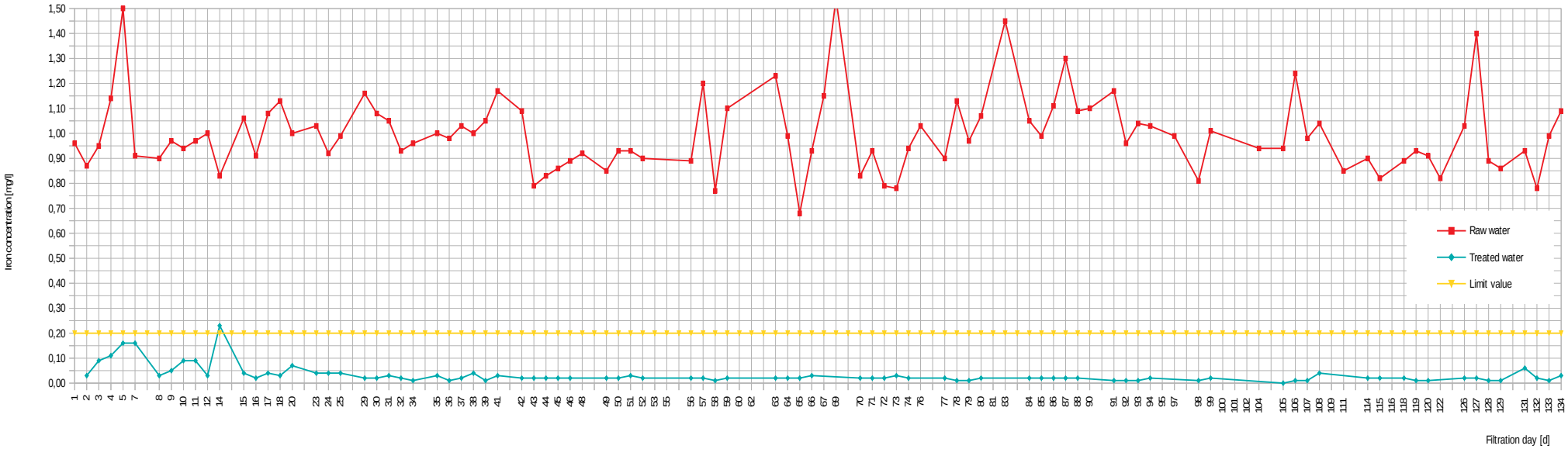
In this paragraph the outlet concentrations of Fe, Mn and NH^{4+} are given for the entire research period for the column operating at 12 m/h with Filtralite Pure HC 0,8-1,6 media. The concentration graphs include the raw water parameters and the regulation limit for treated water.

4.3.1 Iron removal

In order to determine the effect of treatment for iron removal, the concentration of Fe has been monitored daily.

The following graph represents the concentration of iron for the column operating at 12 m/h.

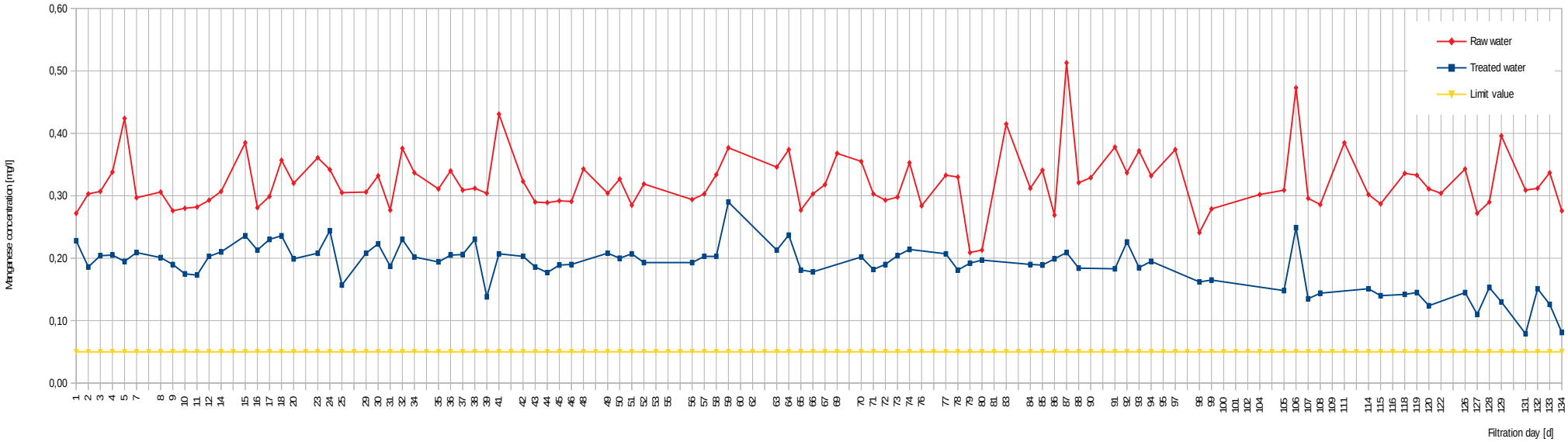
Fig. 8 The effect of treatment for iron removal for the entire research period at 12 m/h filtration rate



4.3.2 Manganese removal

The following graph represents the concentration of manganese for the column operating at 12 m/h.

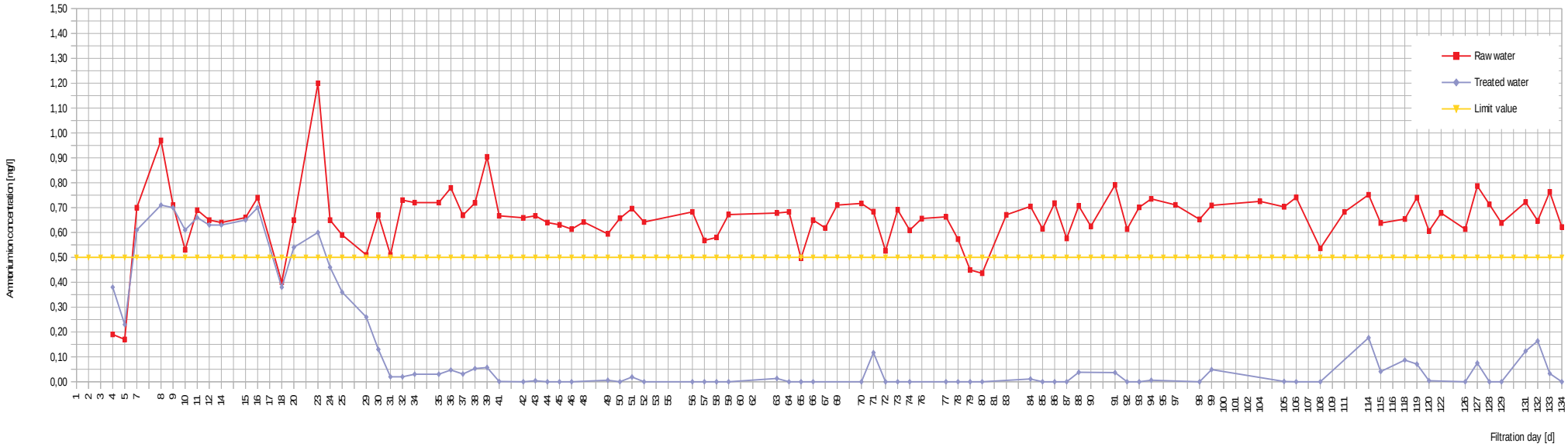
Fig. 9 The effect of treatment for manganese removal for the entire research period at 12 m/h filtration rate



4.3.3 Ammonium ion removal

The following graph represents the concentration of ammonium ion for the column operating at 12 m/h.

Fig. 10 The effect of treatment for ammonium ion removal for the entire research period at 12 m/h filtration rate



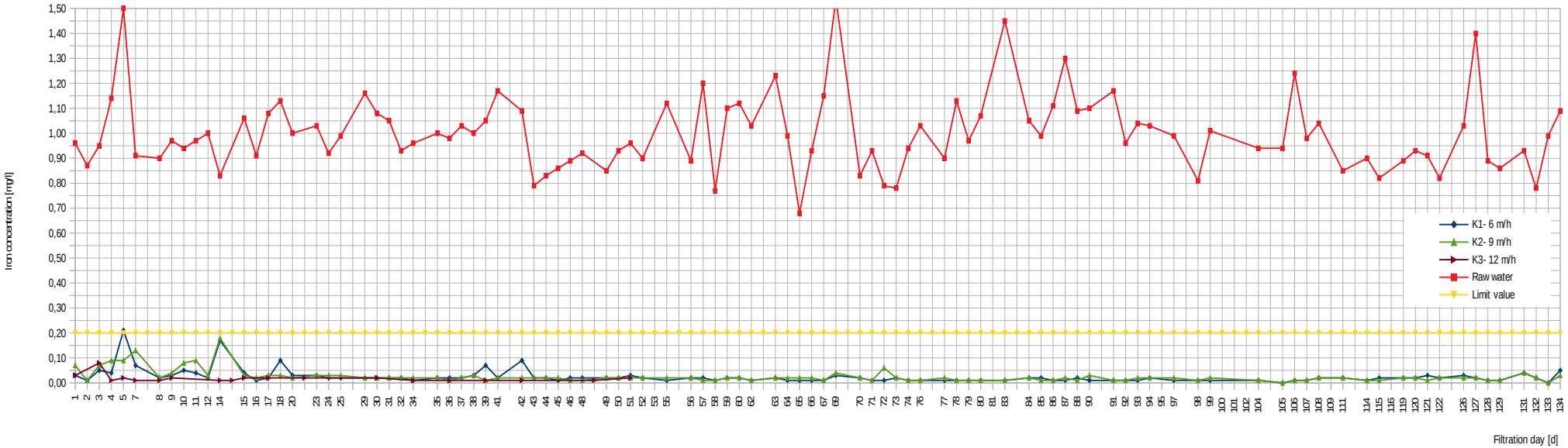
4.4. Comparative study of Fe, Mn and NH^{4+} removal for different filtration rates (6, 9, 12 m/h)

The comparison of the effect of treatment for 6, 9 and 12 m/h filtration rates is presented below. This type of analysis allows to establish the effect of the filtration rate on the treatment process.

4.4.1 Iron removal

The following graph represents the concentration of iron for the column operating at 6, 9 and 12 m/h.

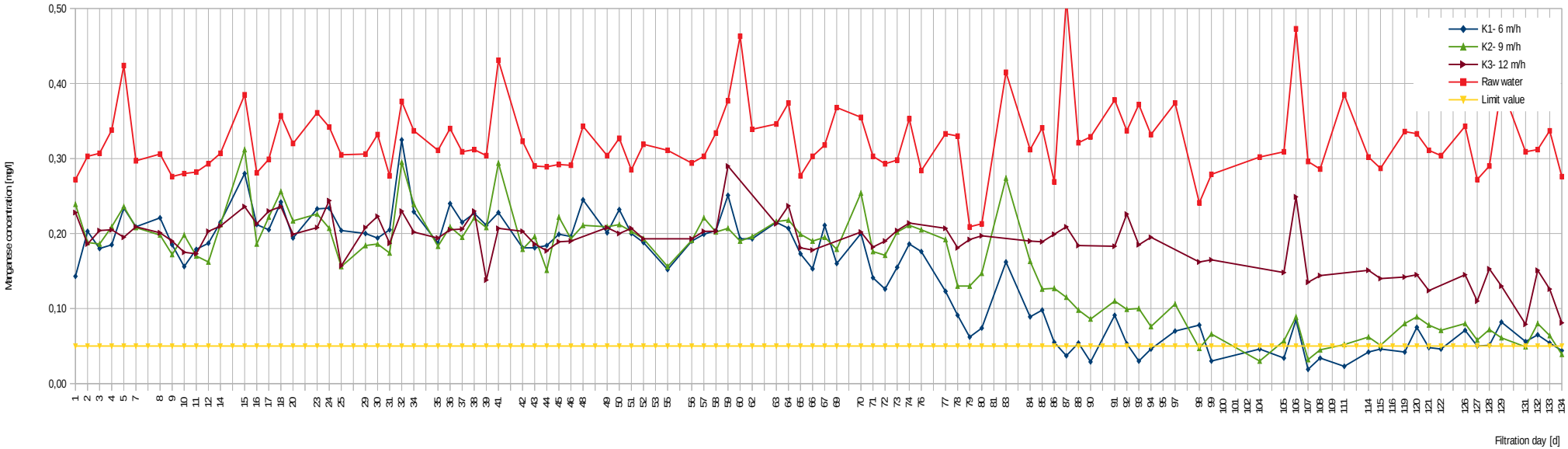
Fig. 11 The effect of treatment for iron removal for the entire research period at 6, 9 and 12 m/h filtration rate



4.4.2 Manganese removal

The following graph represents the concentration of Manganese for the column operating at 6, 9 and 12 m/h.

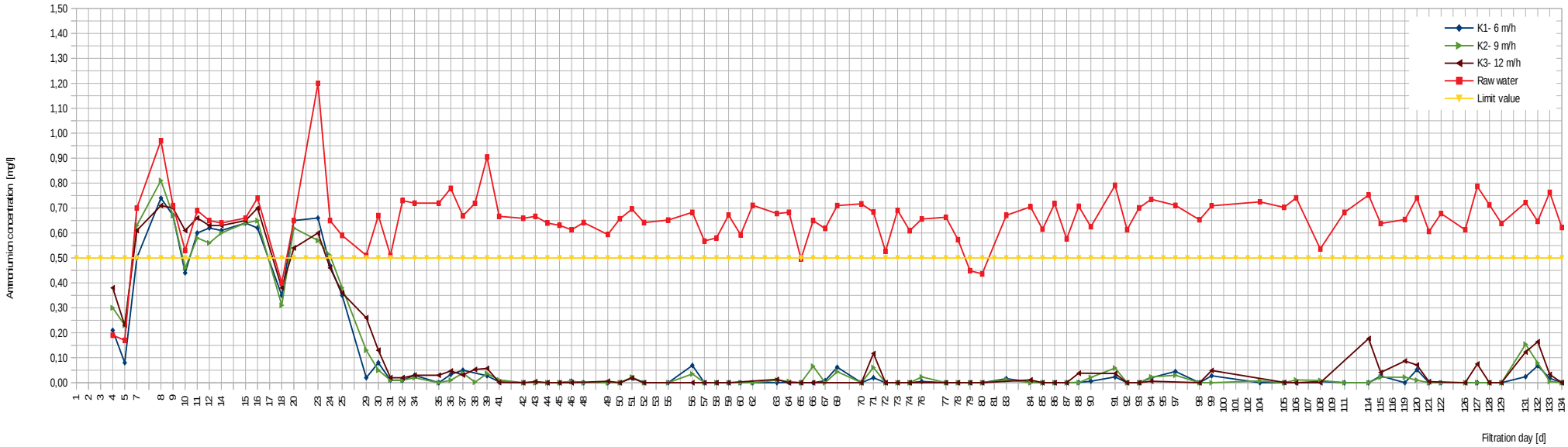
Fig. 12 The effect of treatment for Manganese removal for the entire research period at 6, 9 and 12 m/h filtration rate



4.4.3 Ammonium ion removal

The following graph represents the concentration of Ammonium ion for the column operating at 6, 9 and 12 m/h.

Fig. 13 The effect of treatment for Ammonium ion removal for the entire research period at 6, 9 and 12 m/h filtration rate



4.5. Iron removal layer (zone) for 6 m/h filtration rate

To attain the required iron removal effect of less than 0,2 mgFe/L in treated water, the active iron removal zone must be developed in the top layer of the filter. Thus, iron is removed at earliest in the filtration process.
Deeper layers of the filter should be free of any dissolved iron or iron oxides. This enables the manganese removal process in the bottom layers of the filter.
It is possible to analyze the iron concentration profile at the consecutive depths of the filter with the data collected. The following set of graphs shows the iron removal zone depth for every filtration cycle (16 in total).

Fig. 14 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 1.

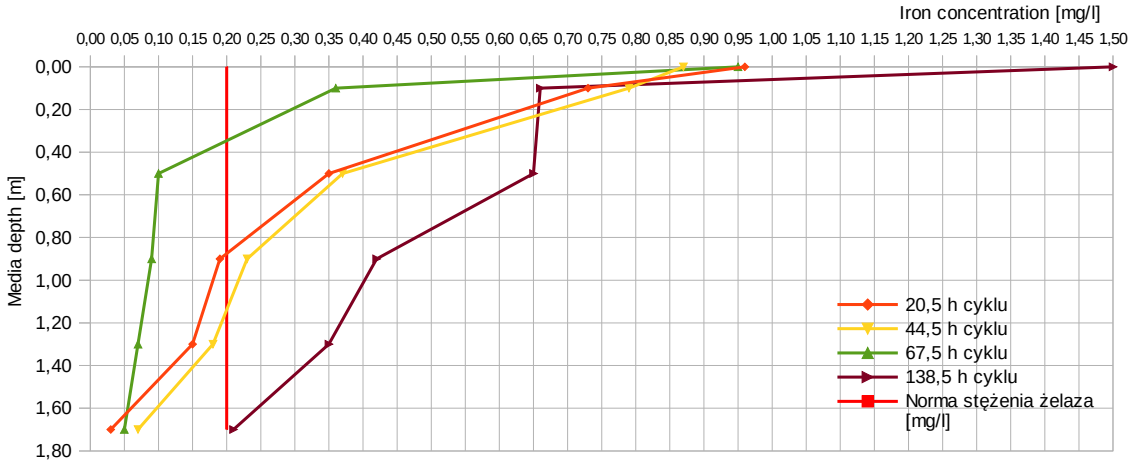


Fig 15. Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 2.

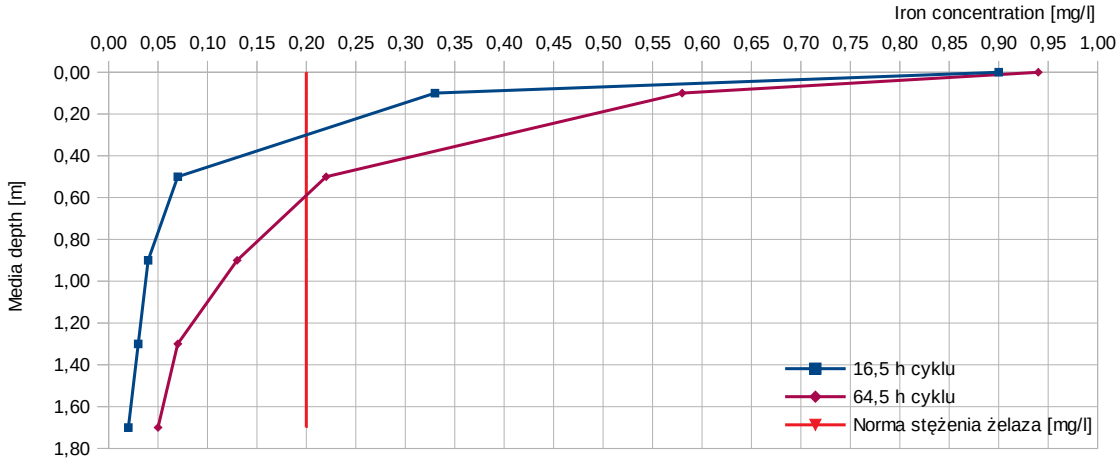


Fig. 16. Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 3.

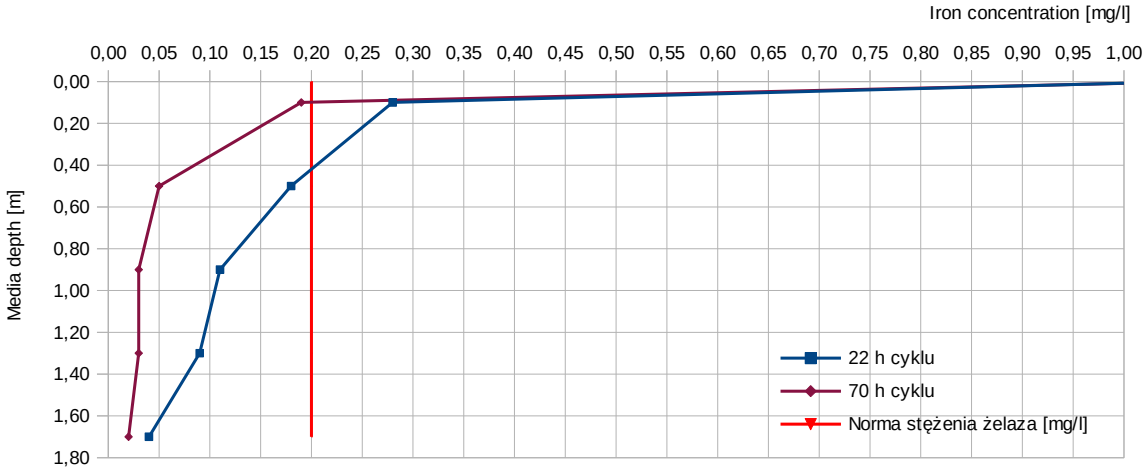


Fig. 17 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 4.

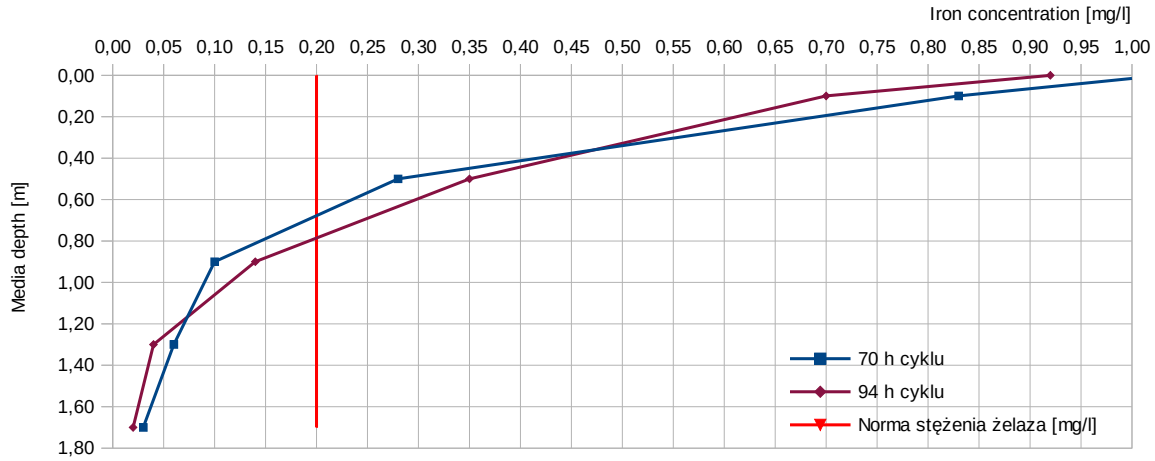


Fig.18 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 5.

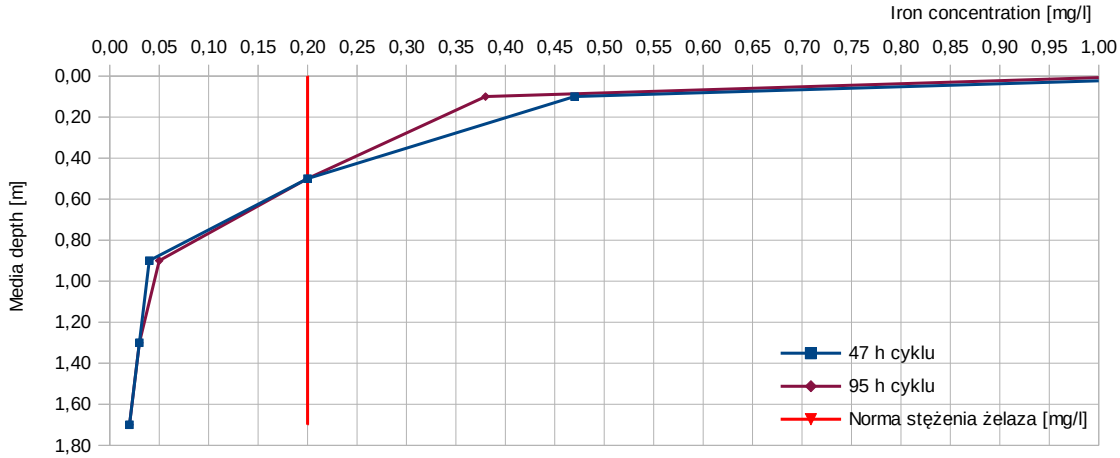


Fig. 19 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 6.

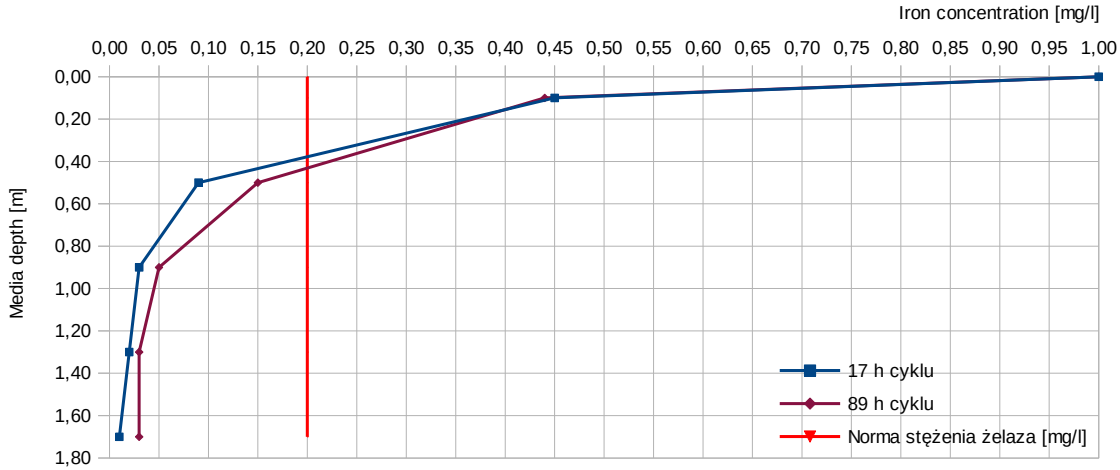


Fig. 20 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 7.

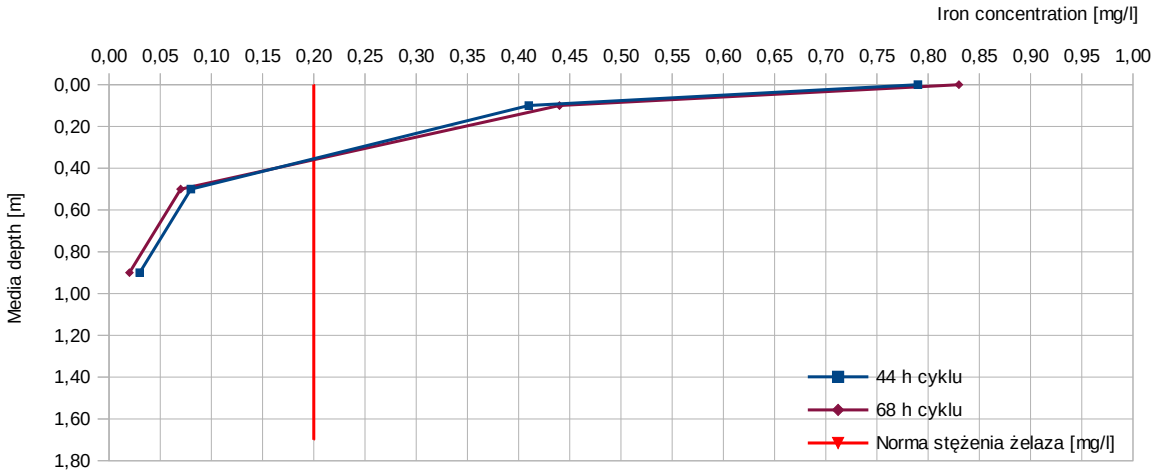


Fig. 21 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 8.

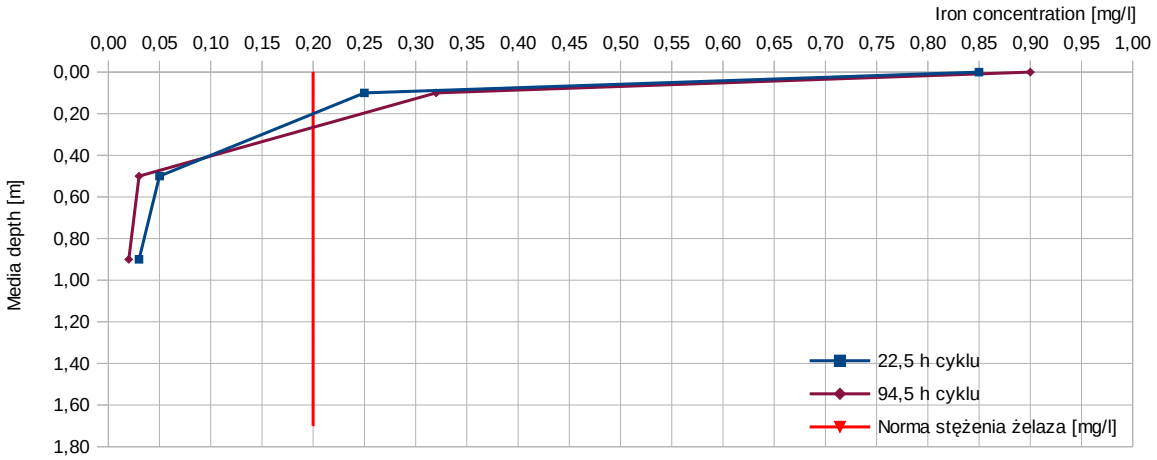


Fig. 22 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 9

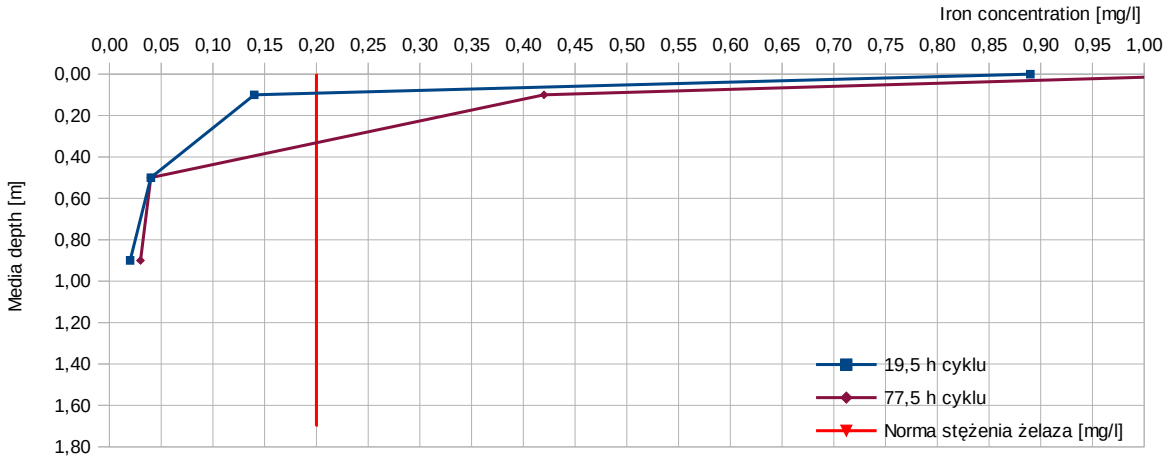


Fig. 23 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 10.

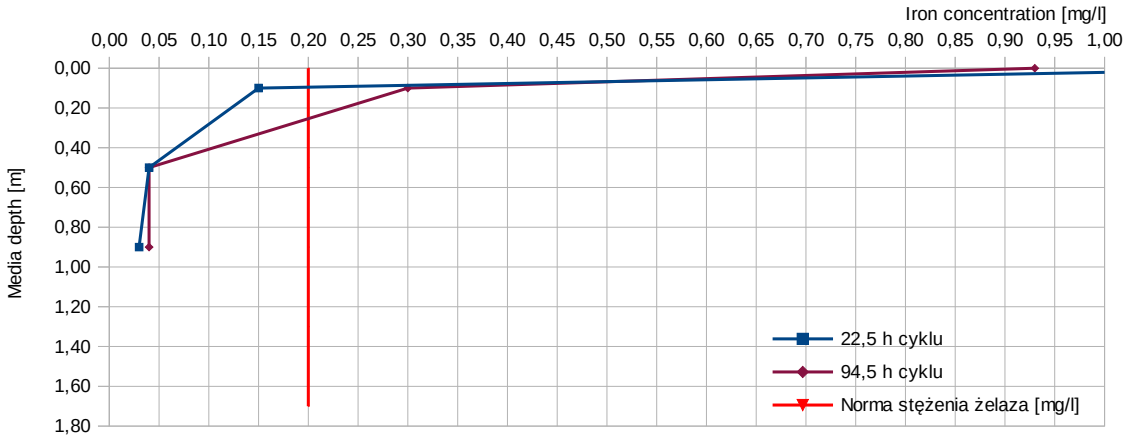


Fig. 24 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 11.

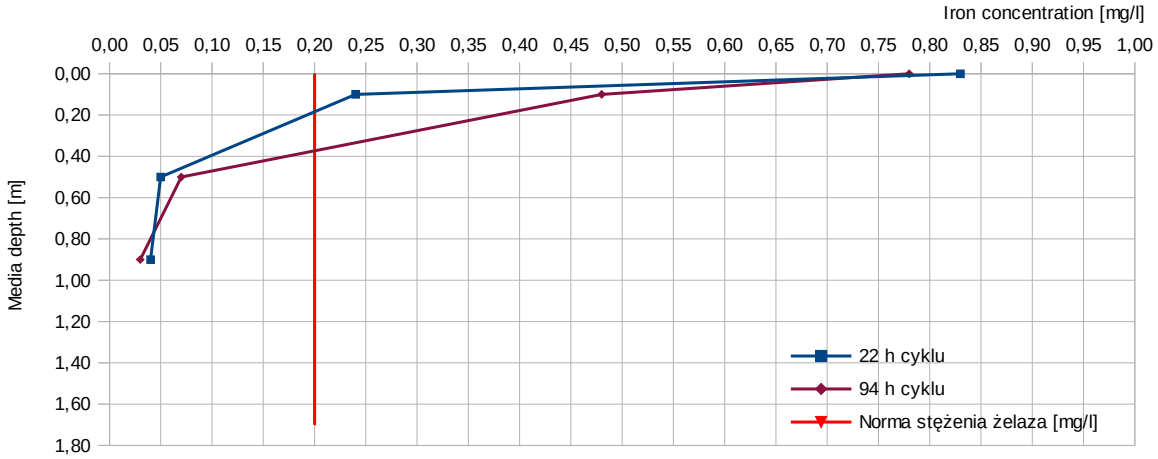


Fig 25 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 12.

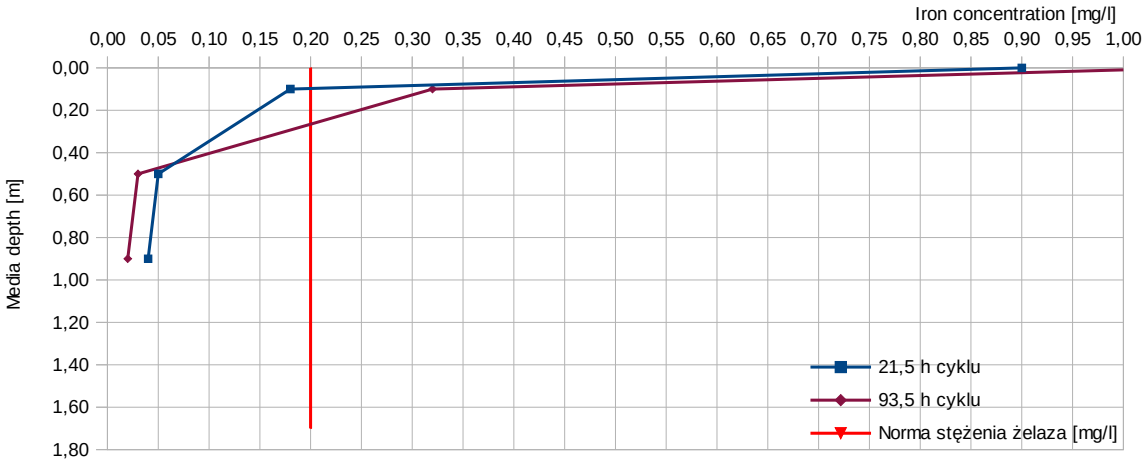


Fig. 26 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 13.

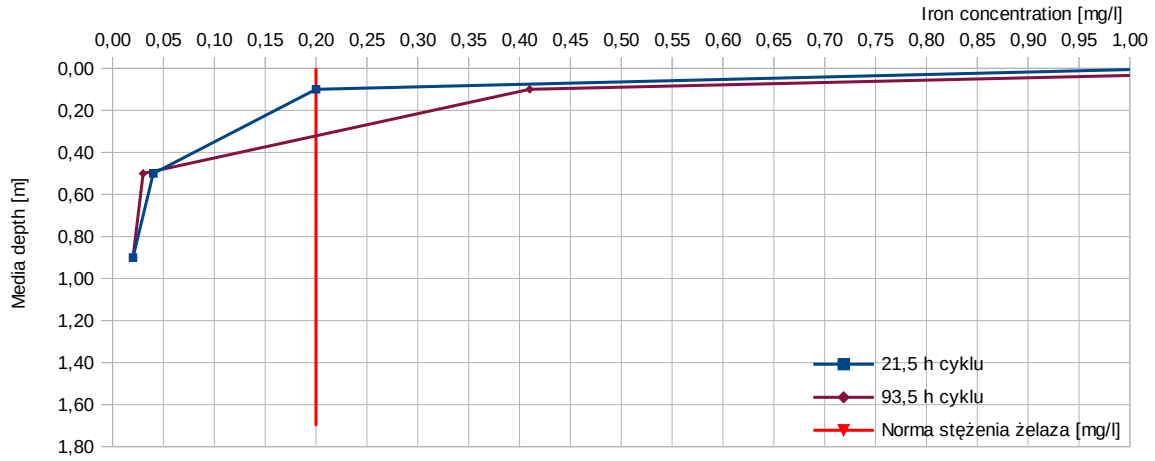


Fig. 27 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 14.

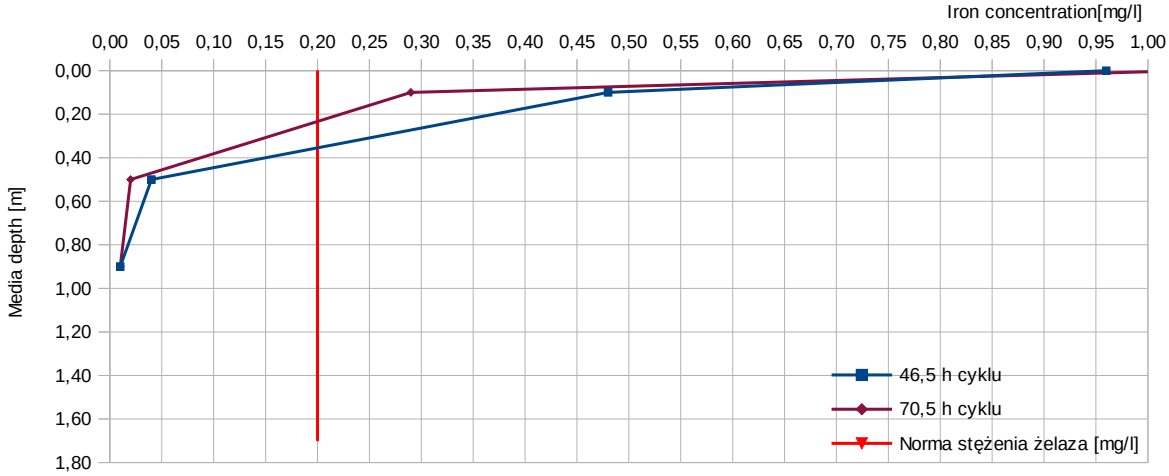


Fig. 28 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 15.

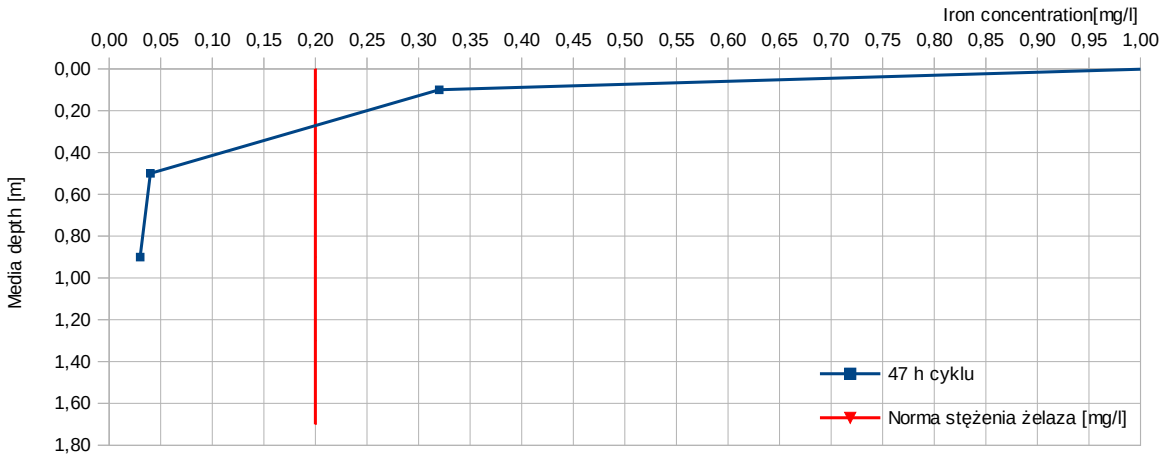
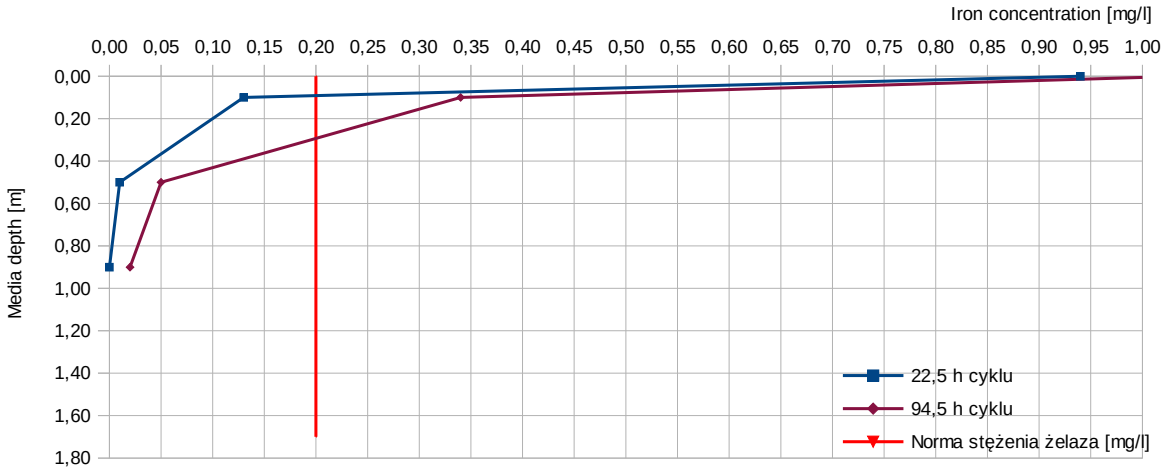


Fig. 29 Iron concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 16.



4.6. Ammonium ion removal layer (zone) for 6 m/h filtration rate

In the work-in for NH^{4+} removal period (filtration cycles 1-4) the analysis was forsaken, because no removal zone could has been identified anyway.
Upon noticing the removal effectiveness in the filtration cycle no.5, the analysis has been conducted.

The following set of graphs shows the ammonium ion removal zone depth for filtration cycles 5-15.

Fig. 30 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 5.

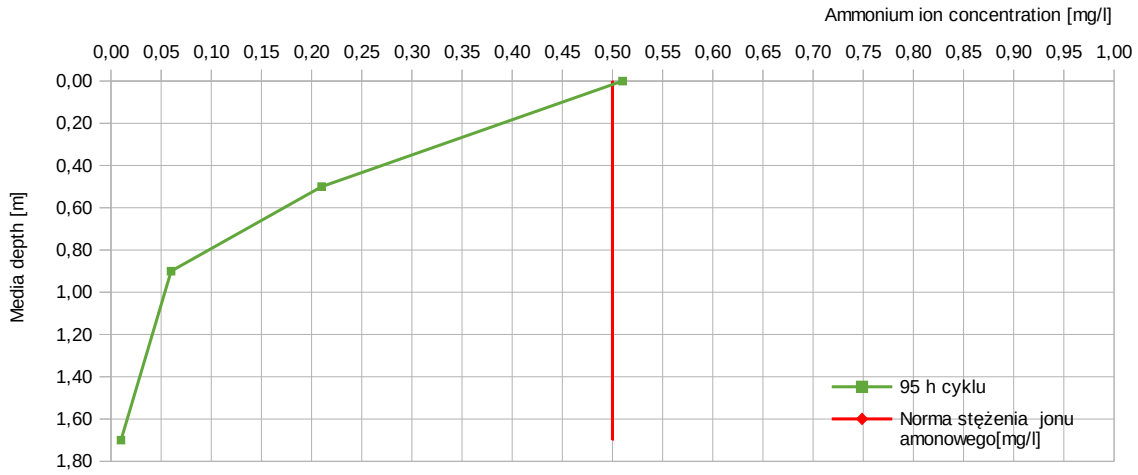


Fig. 31 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 6.

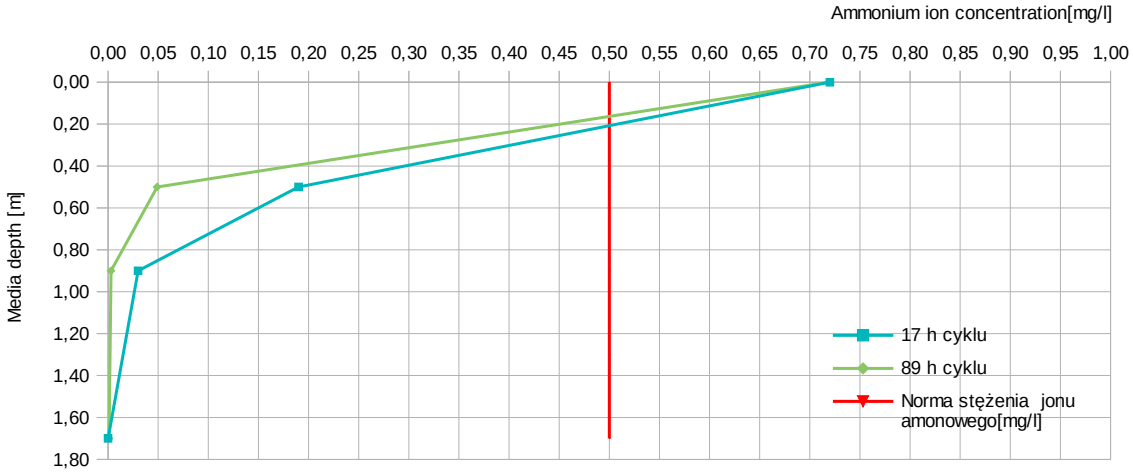


Fig. 32 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 7.

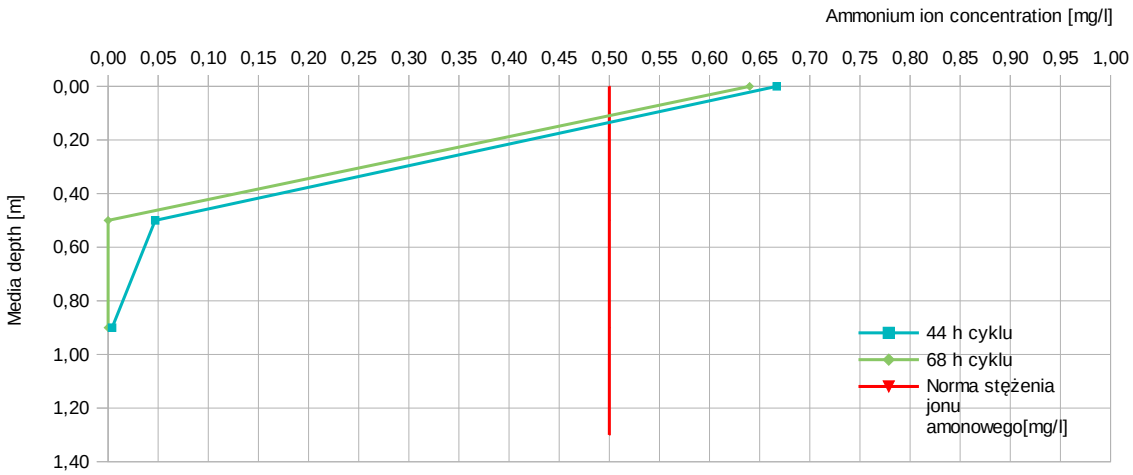


Fig. 33 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 8.

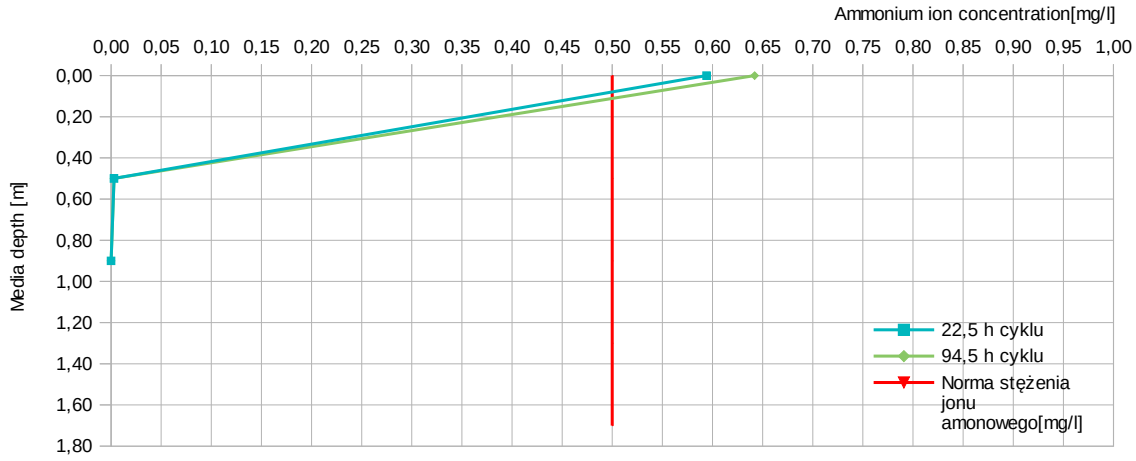


Fig.34 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 9.

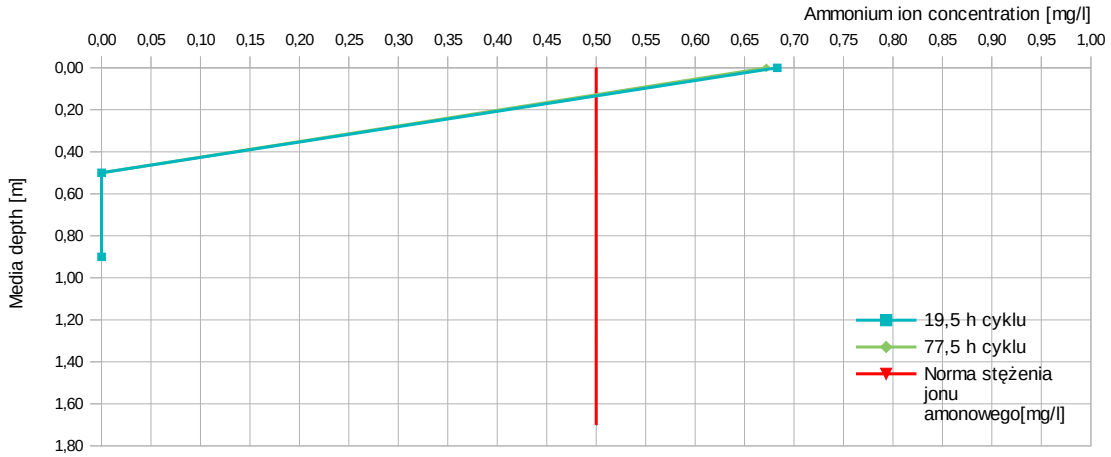


Fig. 35 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 10.

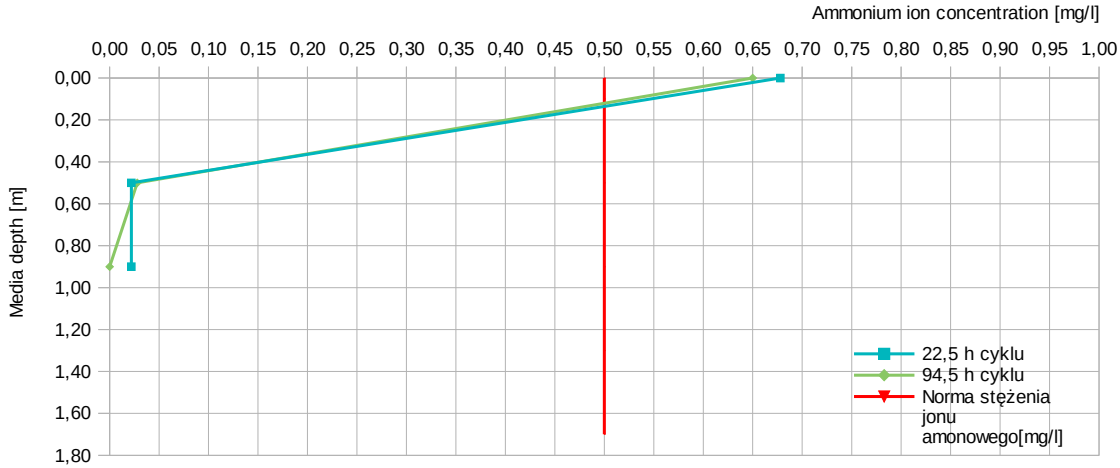


Fig. 36 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 11.

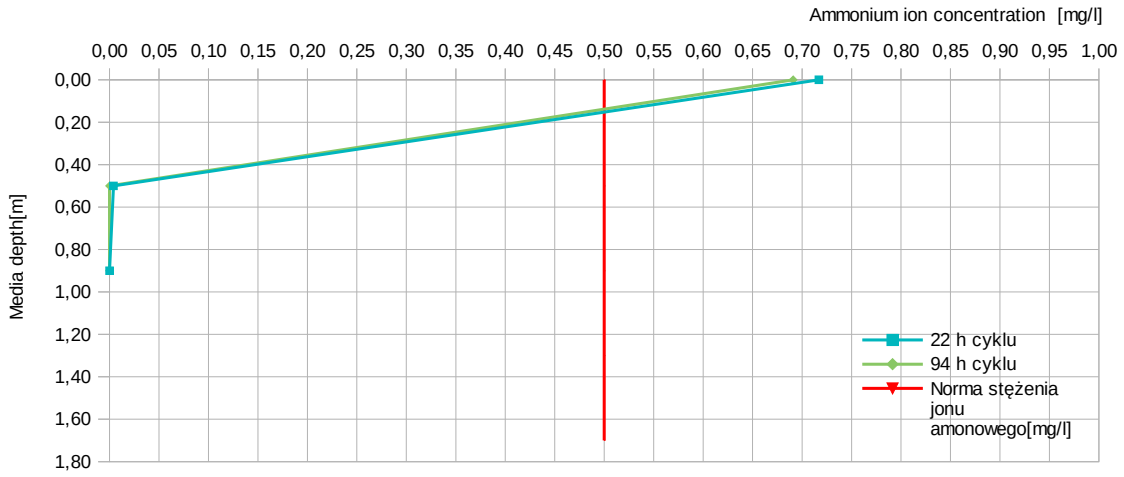


Fig. 37Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 12.

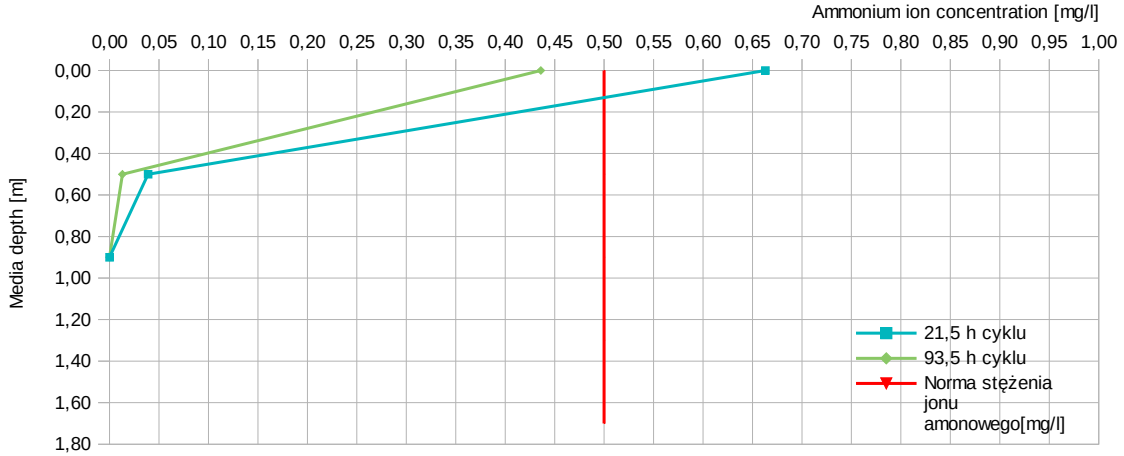


Fig. 38 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 13.

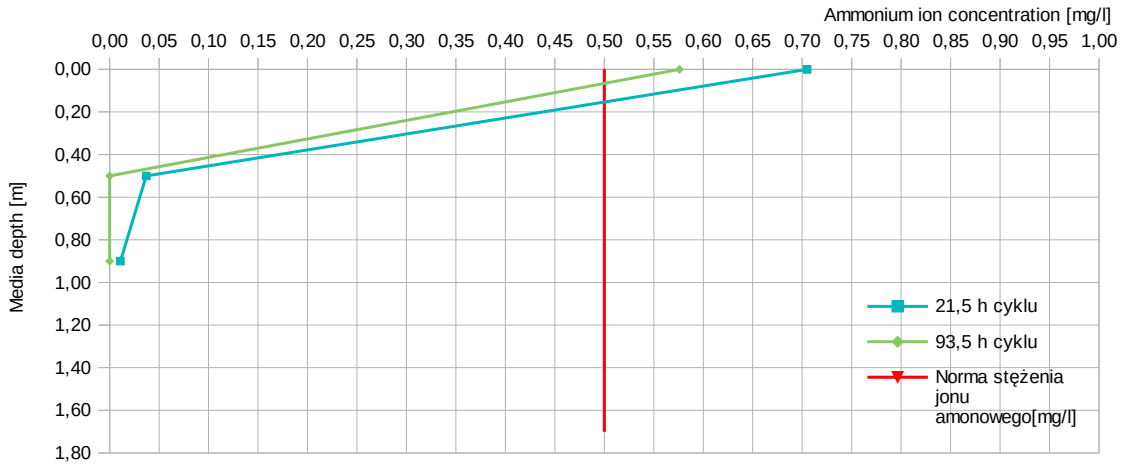


Fig. 39 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 14.

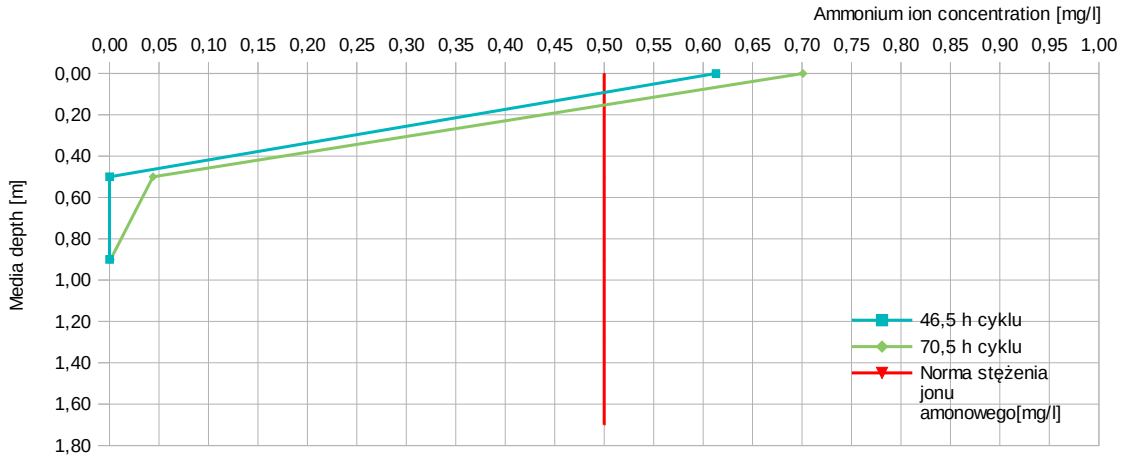


Fig. 40 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 15.

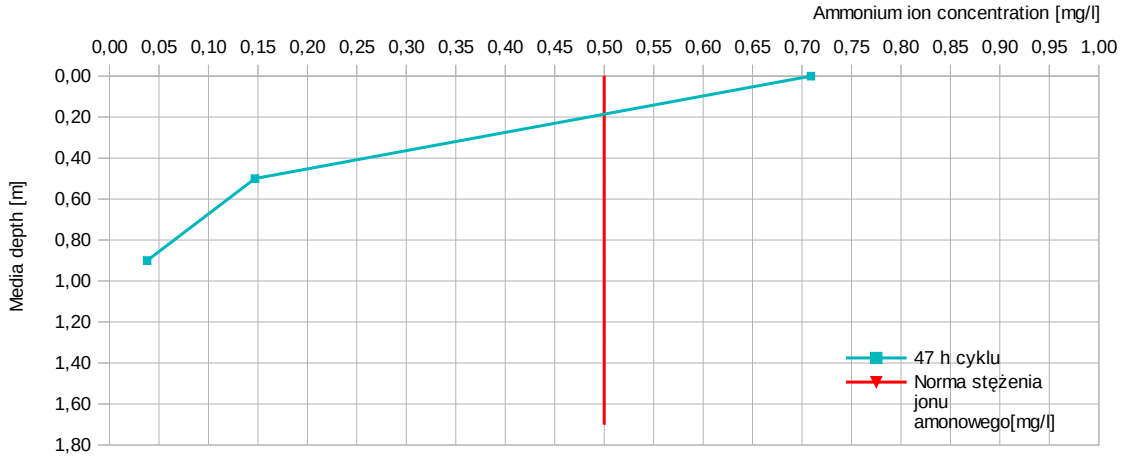
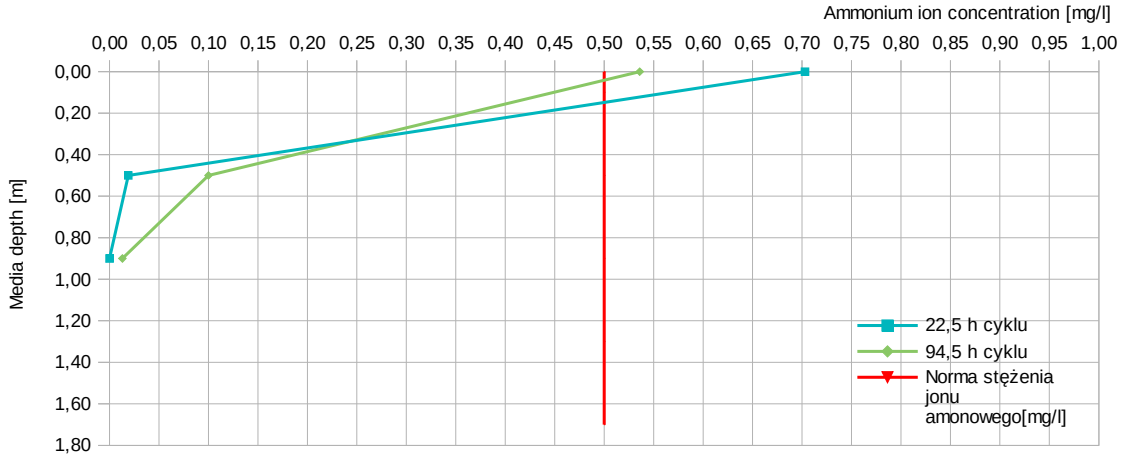


Fig. 41 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 16.



4.7. Manganese removal layer (zone) for 6 m/h filtration rate

In the work-in for Mn removal period (filtration cycles 1-12) the analysis was forsaken, because no removal zone could has been identified anyway.

Upon noticing the removal effectiveness in the filtration cycle no. 13, the analysis has been conducted.

The following set of graphs shows the manganese removal zone depth for filtration cycles 13-15.

Fig. 42 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 13.

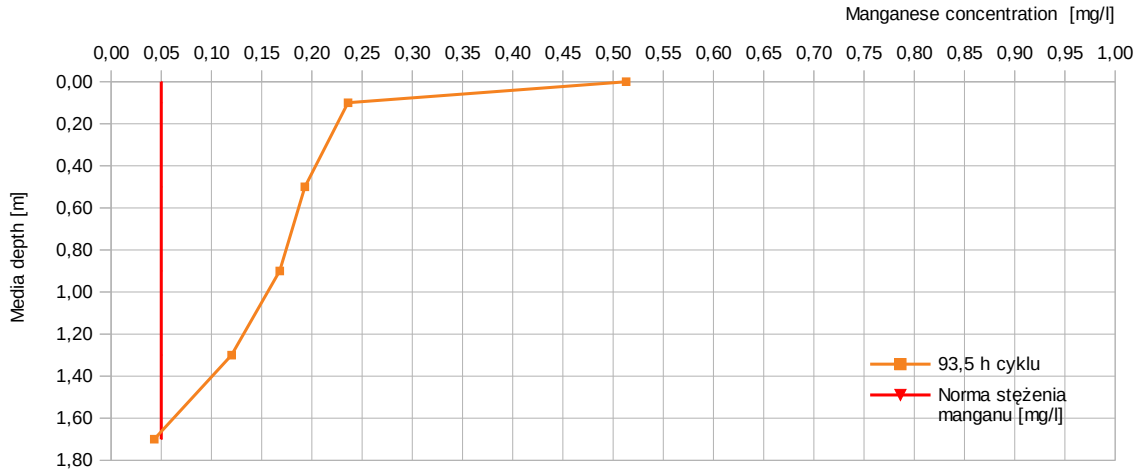


Fig. 43 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 14.

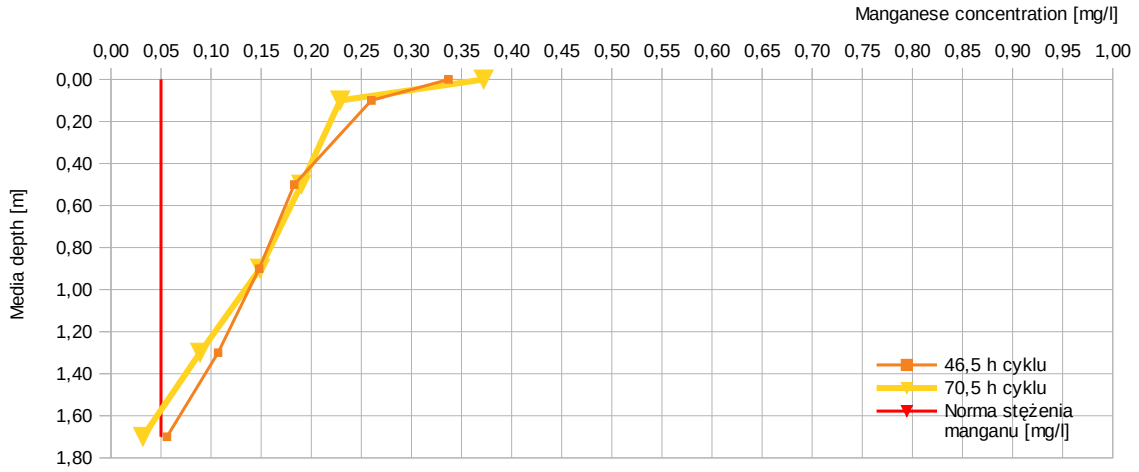


Fig. 44 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 15.

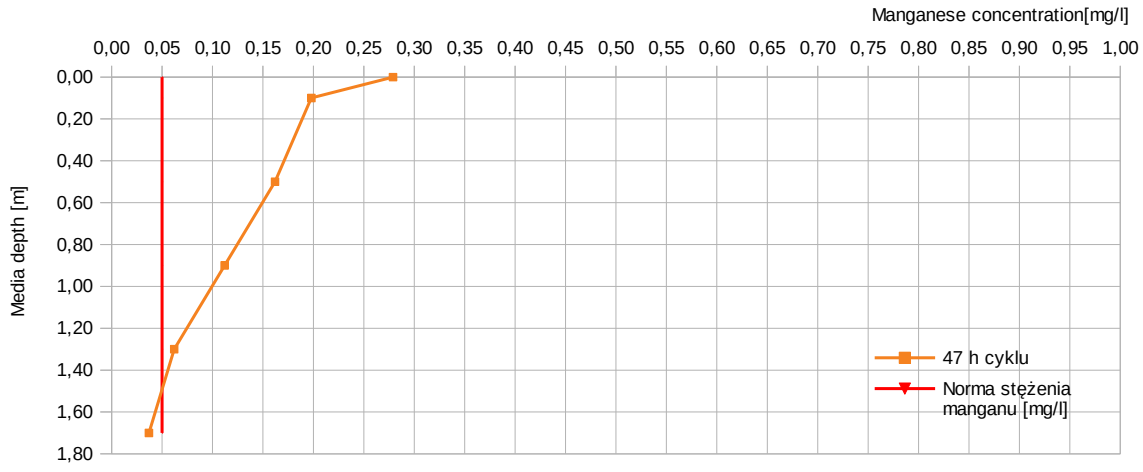


Fig. 45. Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 16.

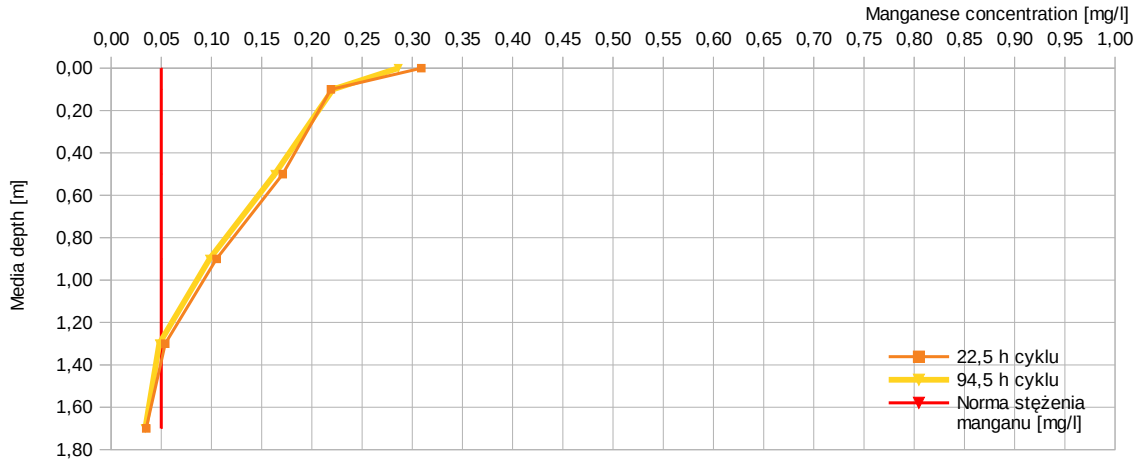


Fig 46. Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 17.

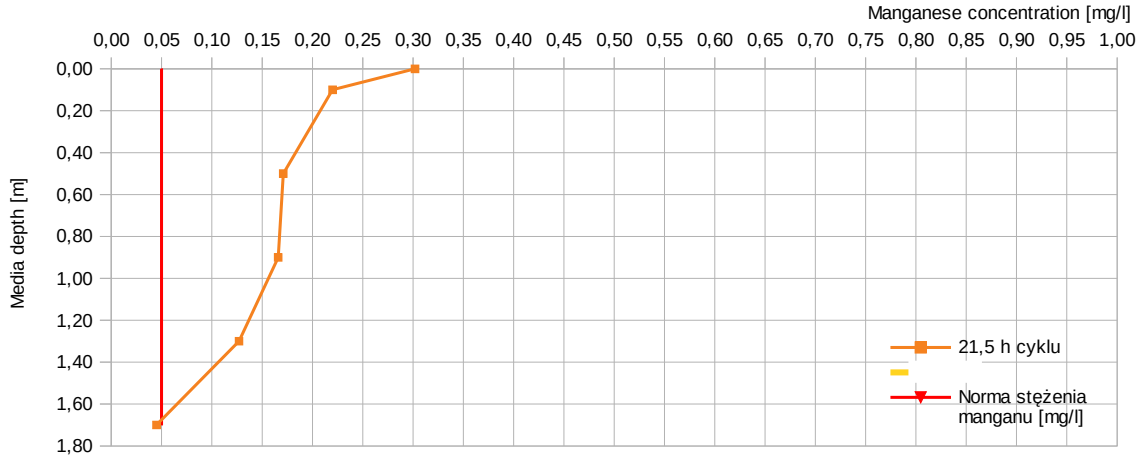


Fig.47 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 18.

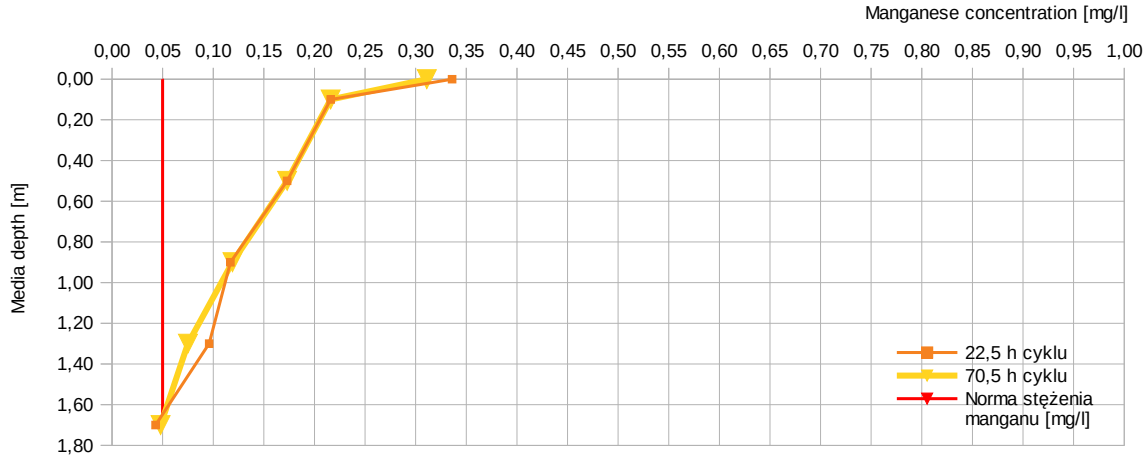


Fig. 48 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 19.

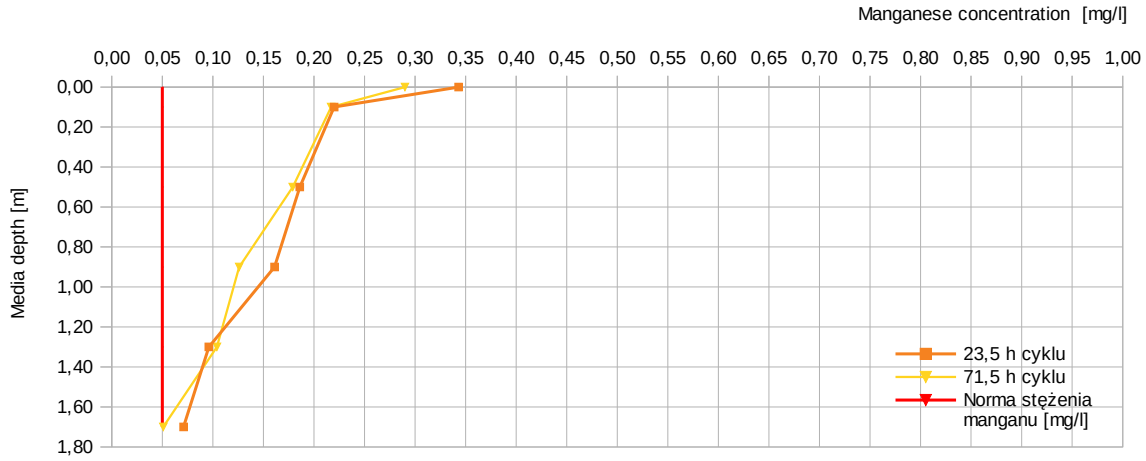


Fig. 49 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 20.

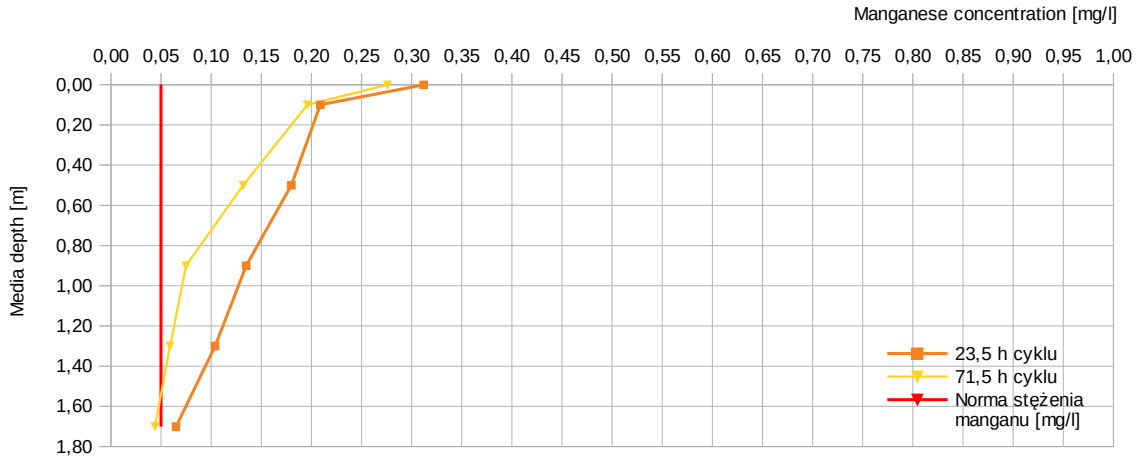
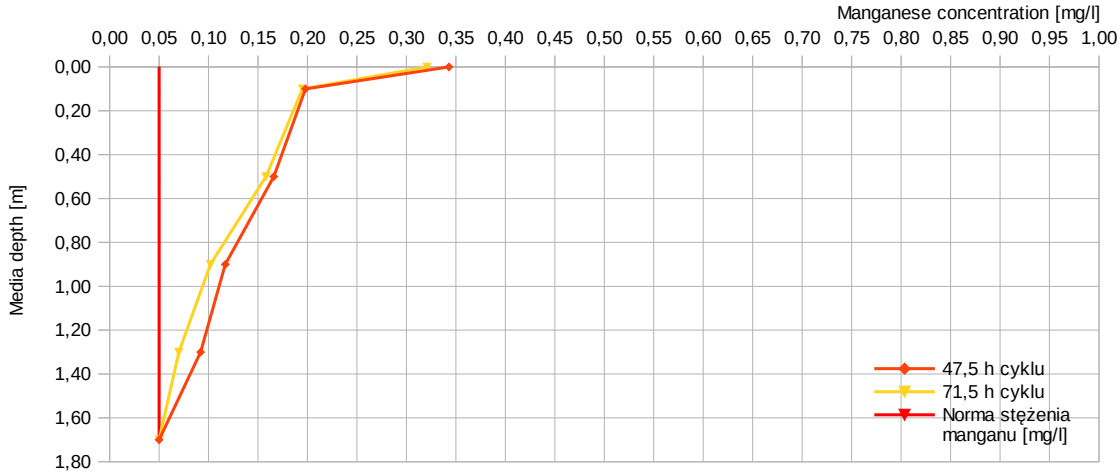


Fig 50 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 6 m/h, filtration cycle no. 21.



4.8. Iron removal layer (zone) for 9 m/h filtration rate

The following set of graphs shows the iron removal zone depth for every filtration cycle (16 in total) for 9m/h filtration rate.

Fig. 51 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 1.

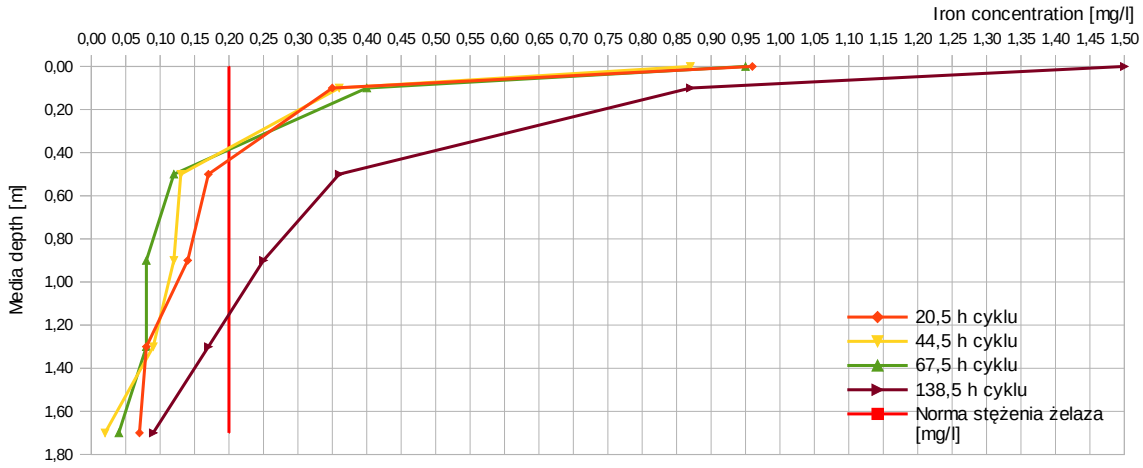


Fig.52 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 2.

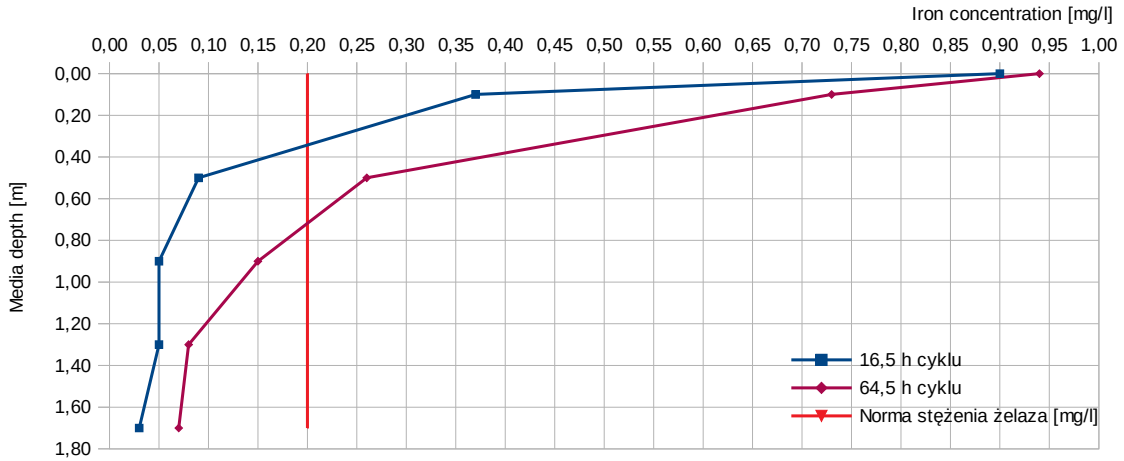


Fig. 53 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 3.

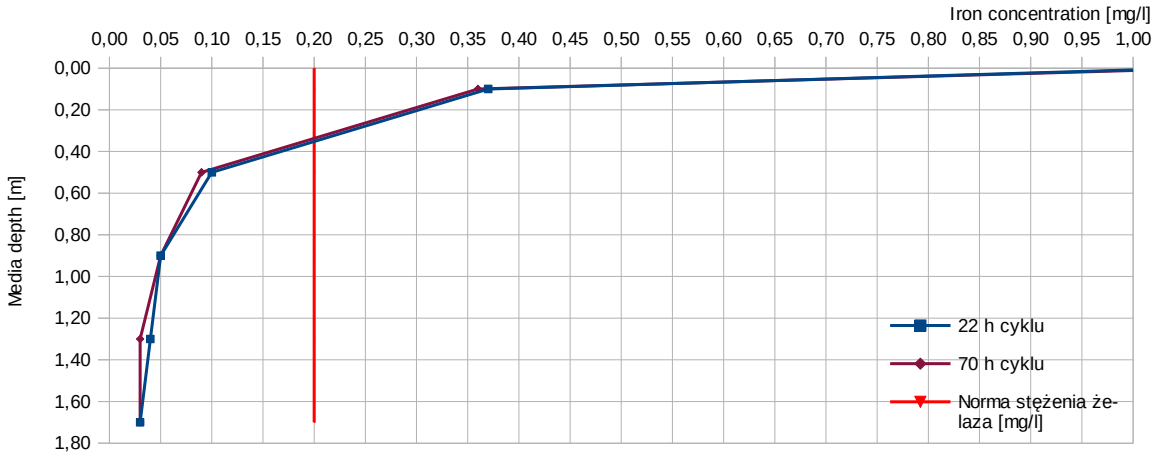


Fig. 54 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 4.

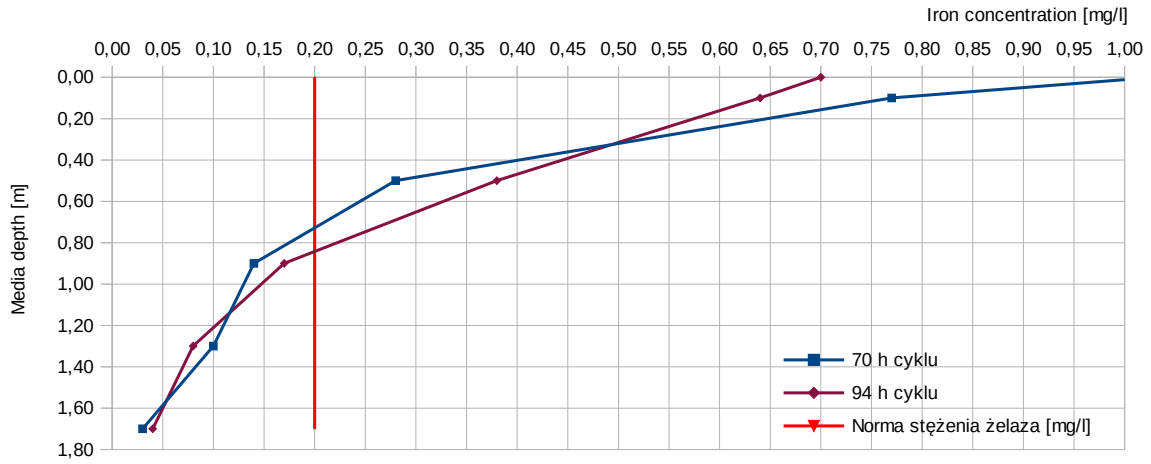


Fig. 55. Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 5.

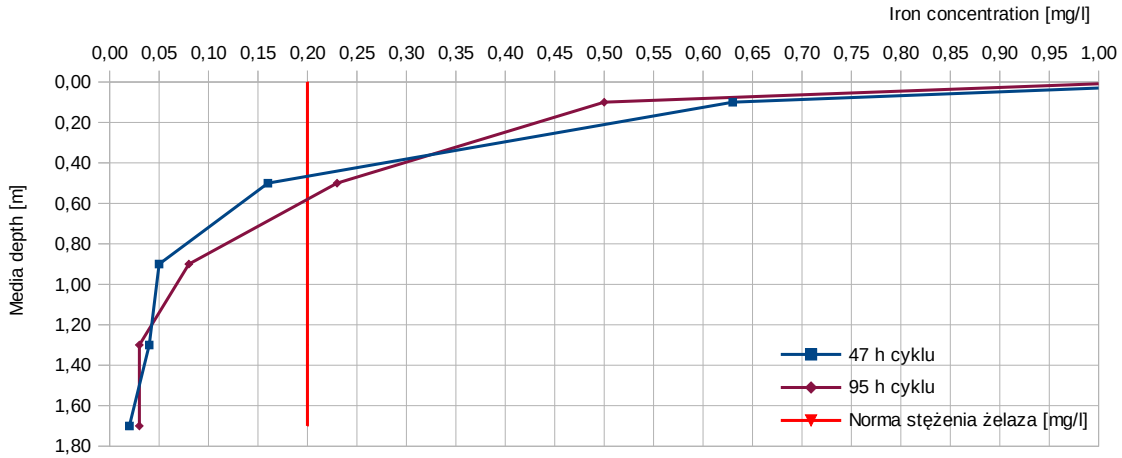


Fig 56. Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 6.

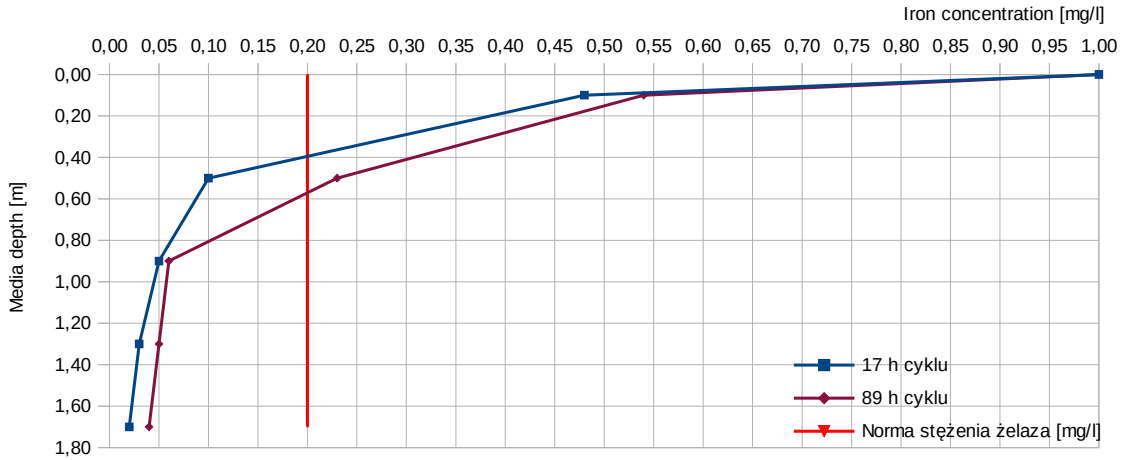


Fig. 57. Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 7.

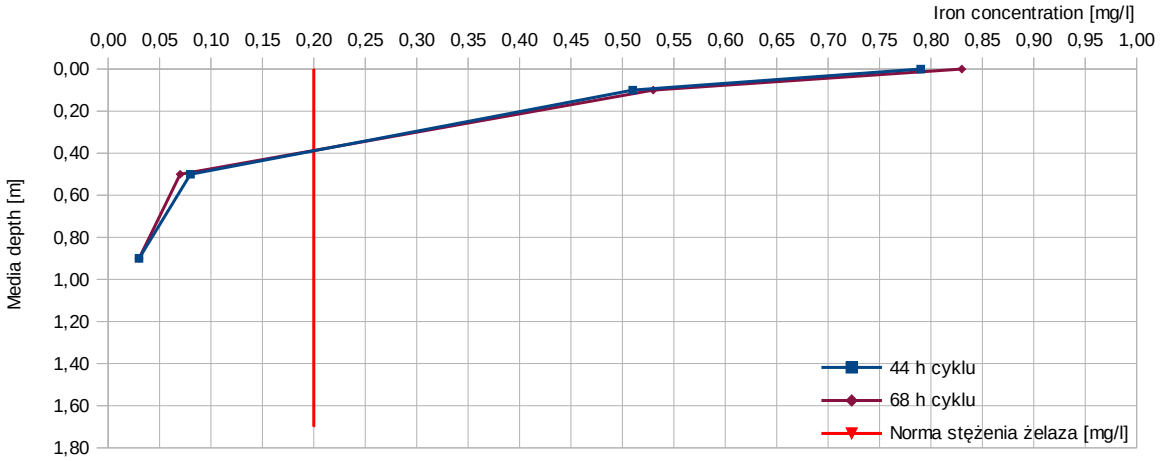


Fig. 58 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 8.

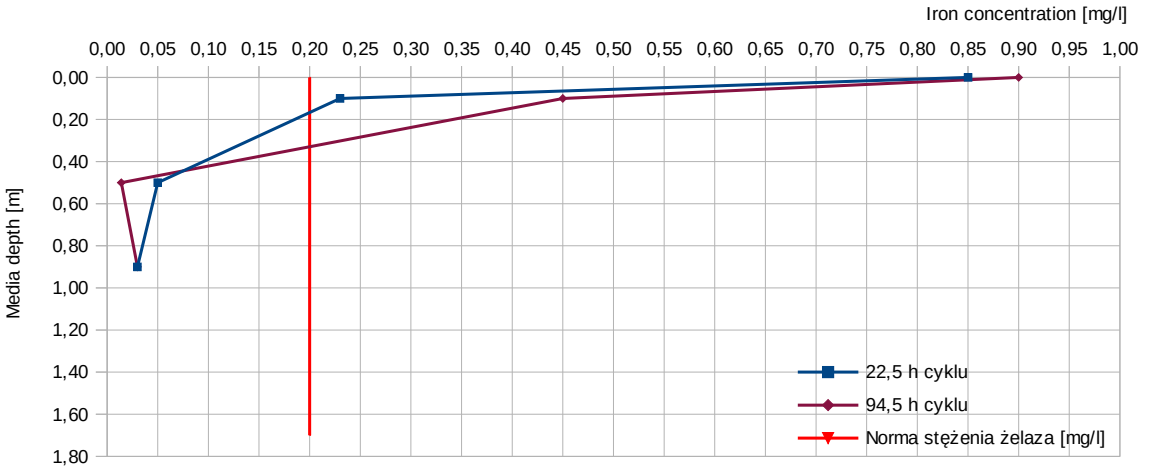


Fig. 59 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 9.

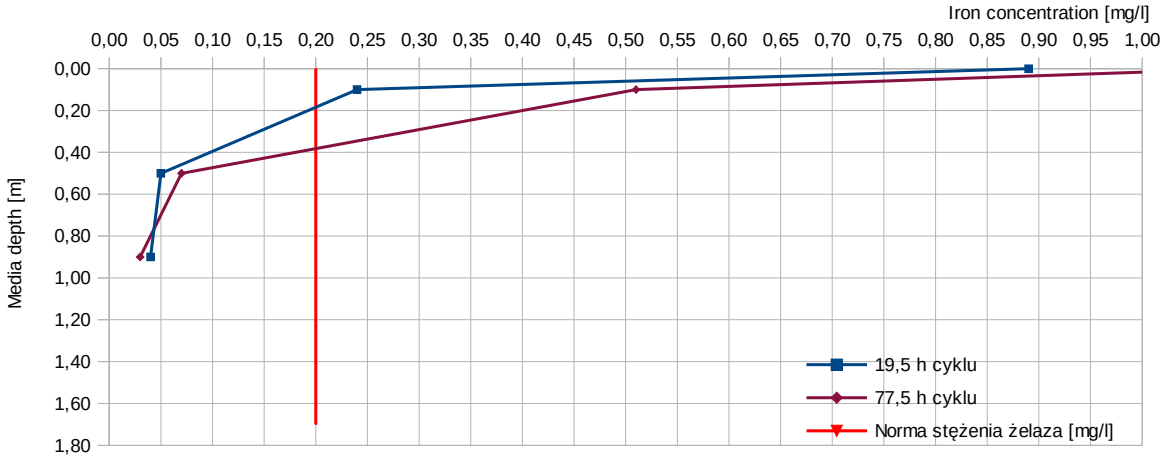


Fig. 60 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 10.

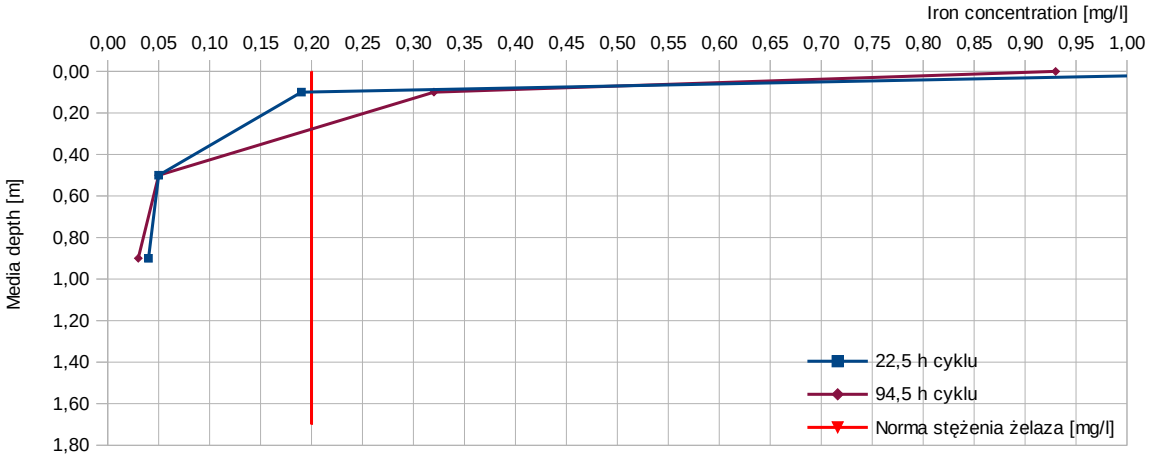


Fig. 61 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 11.

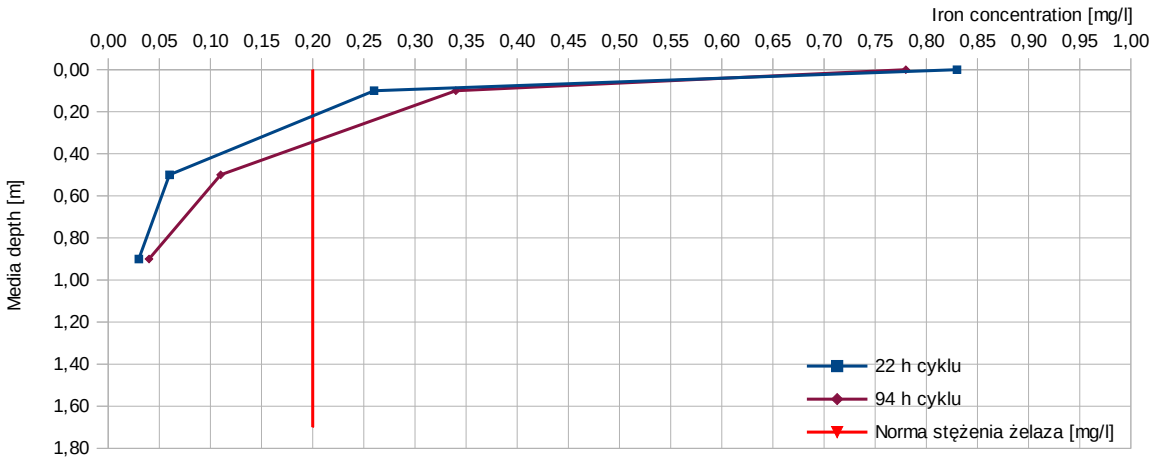


Fig 62 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 12.

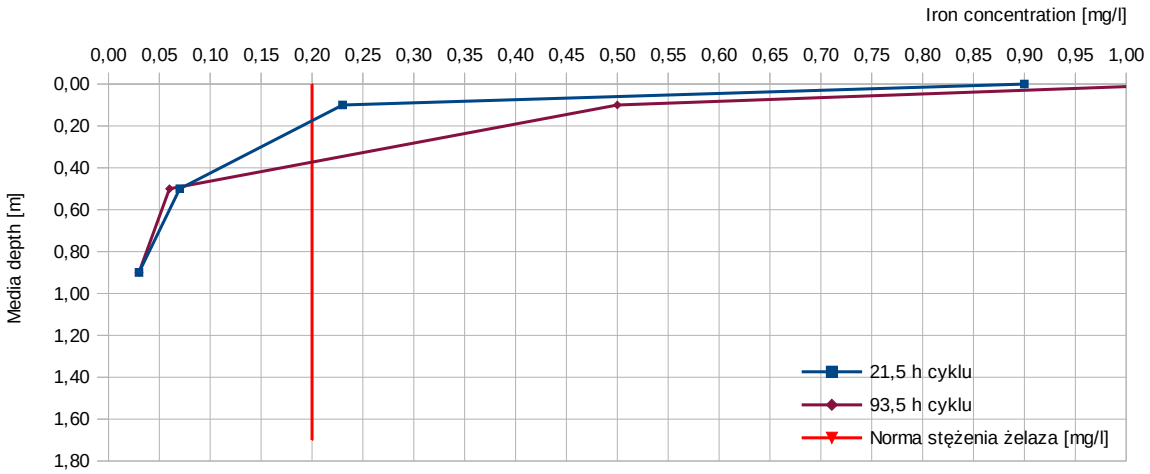


Fig. 63 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 13.

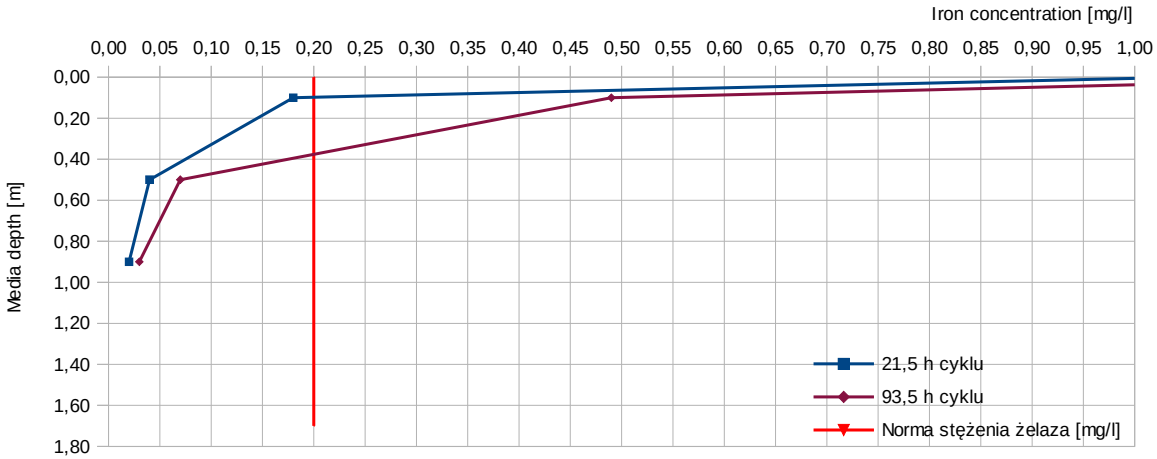


Fig. 64 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 14.

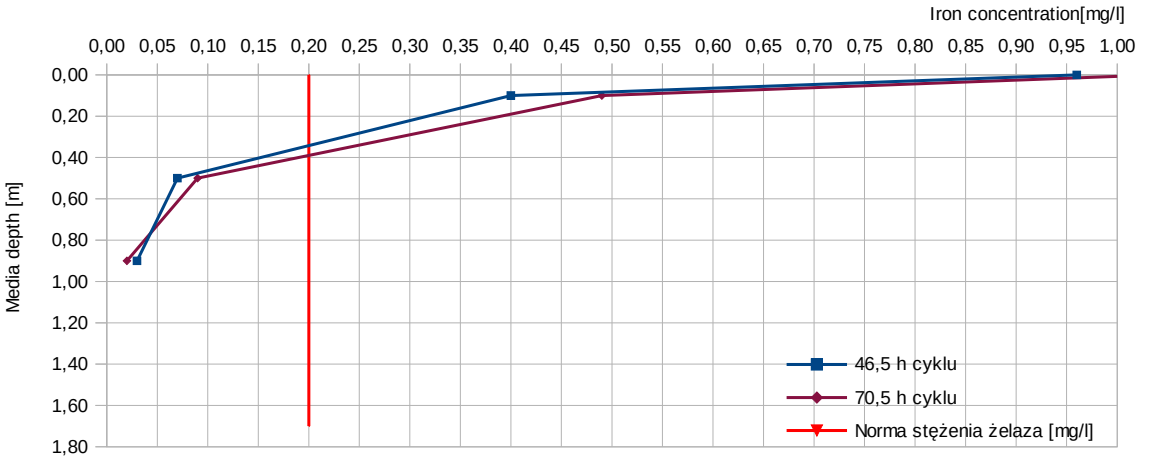


Fig. 65 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 15.

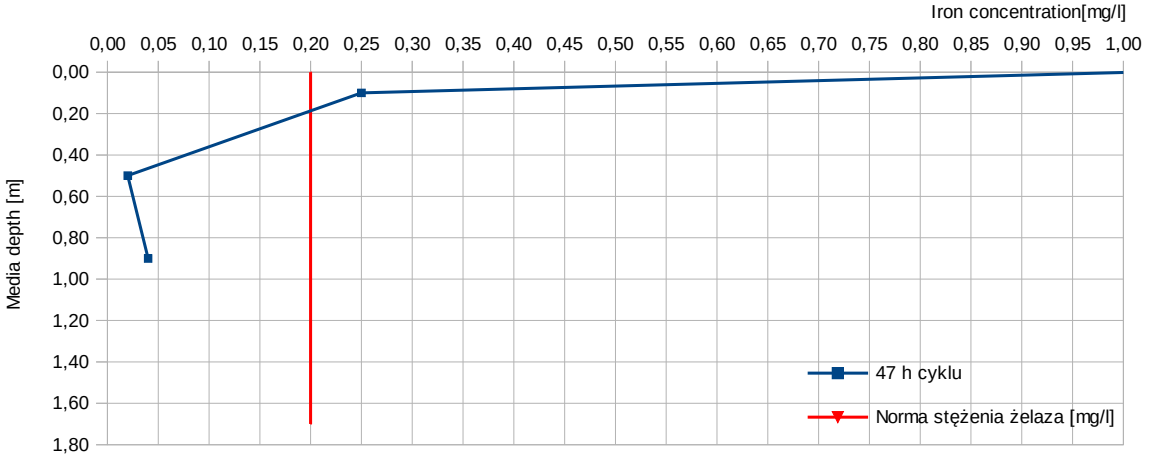
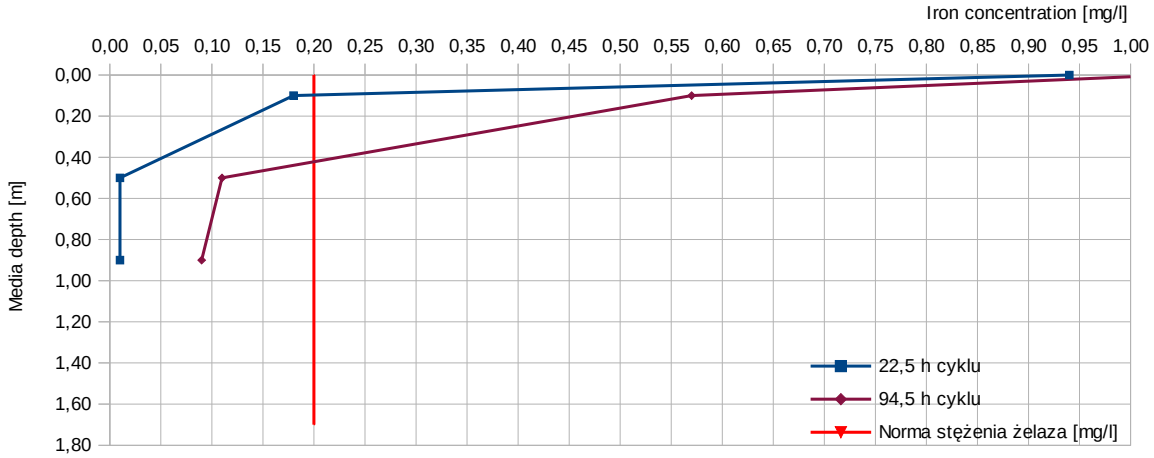


Fig. 66 Iron concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 16.



4.9. Ammonium ion removal layer (zone) for 9 m/h filtration rate

In the work-in for NH^{4+} removal period (filtration cycles 1-4) the analysis was forsaken, because no removal zone could has been identified anyway.

Upon noticing the removal effectiveness in the filtration cycle no.5, the analysis has been conducted.

The following set of graphs shows the ammonium ion removal zone depth for filtration cycles 5-15.

Fig. 67 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 5

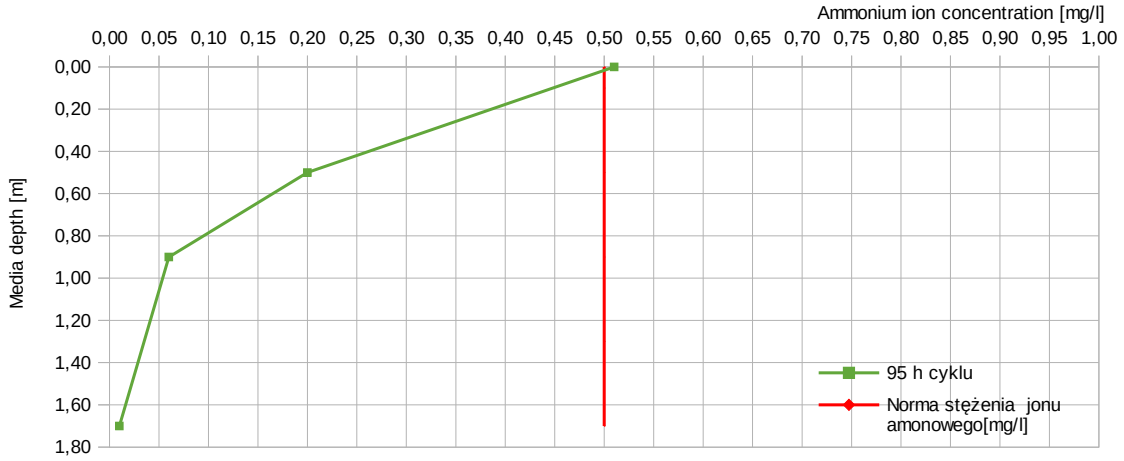


Fig. 68. Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 6

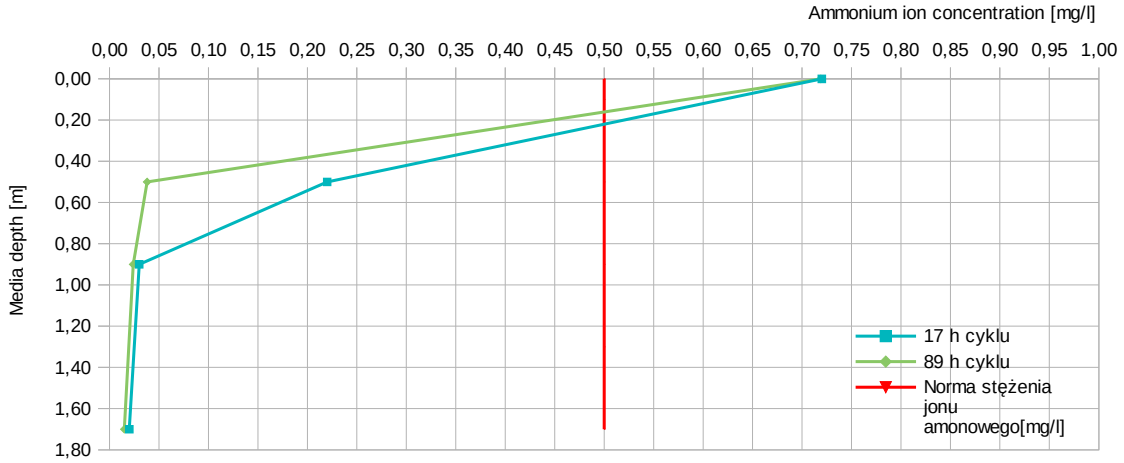


fig.69 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 7

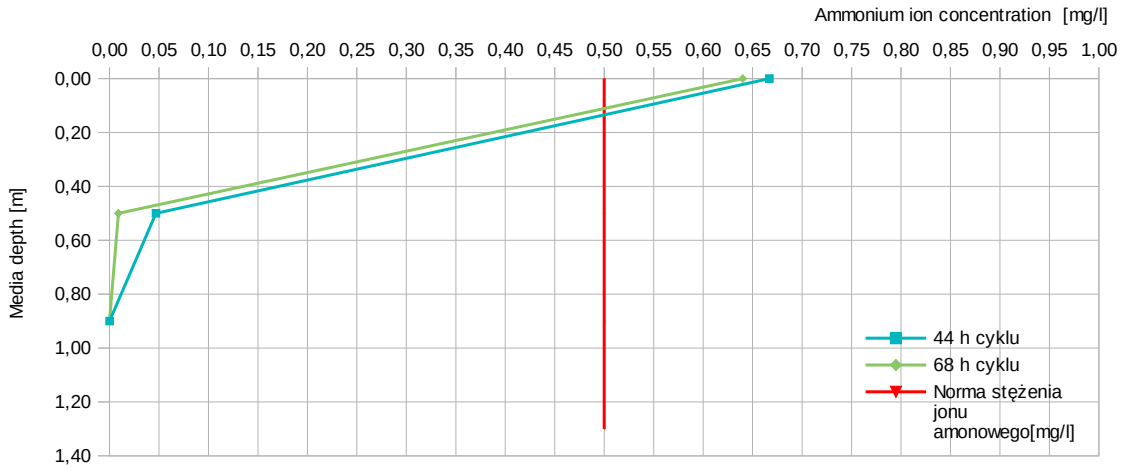


Fig. 70 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 8

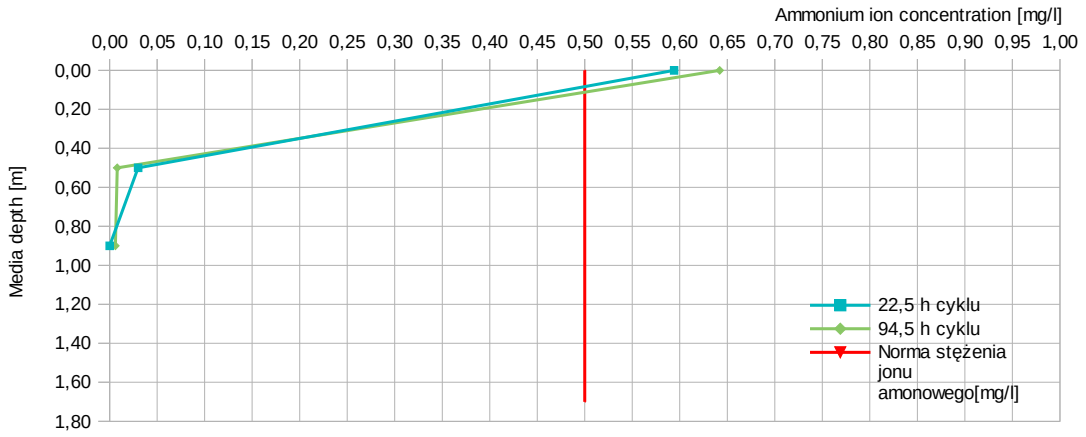


Fig. 71 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 9

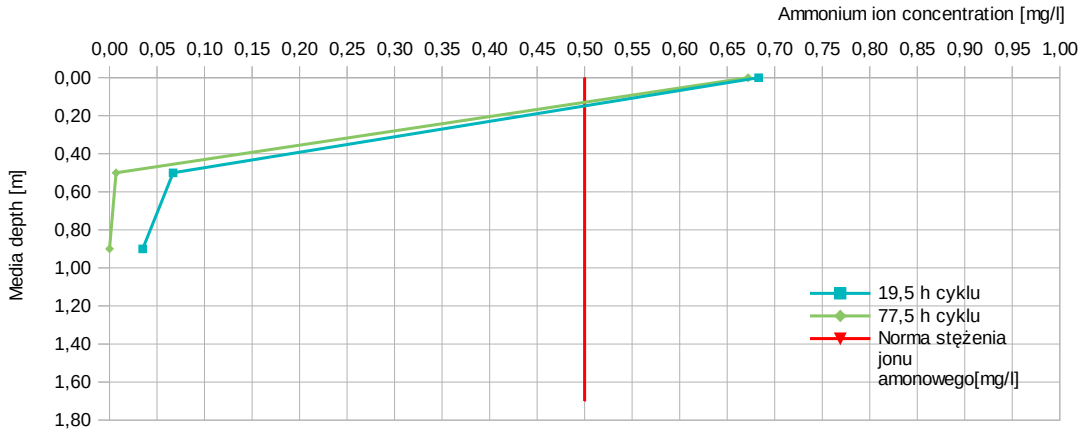


Fig.72 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 10

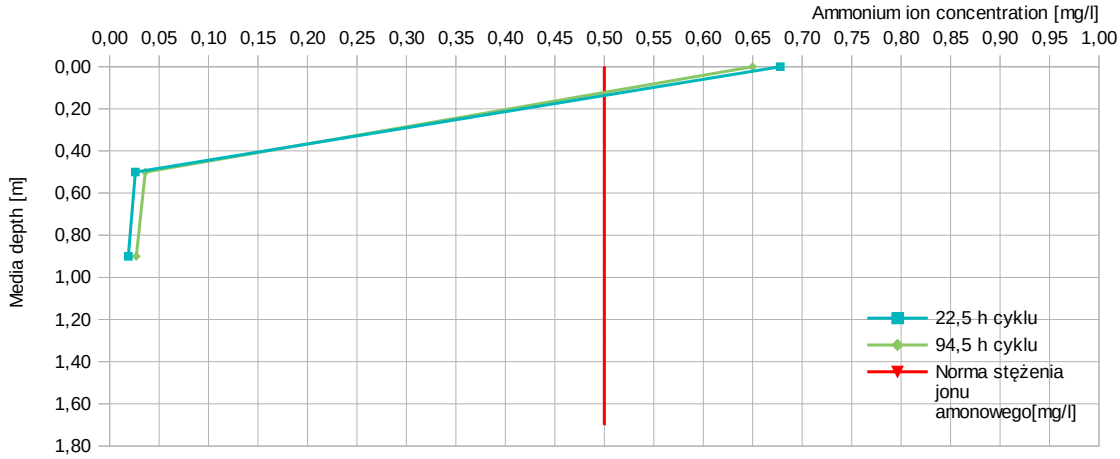


Fig. 73 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 11

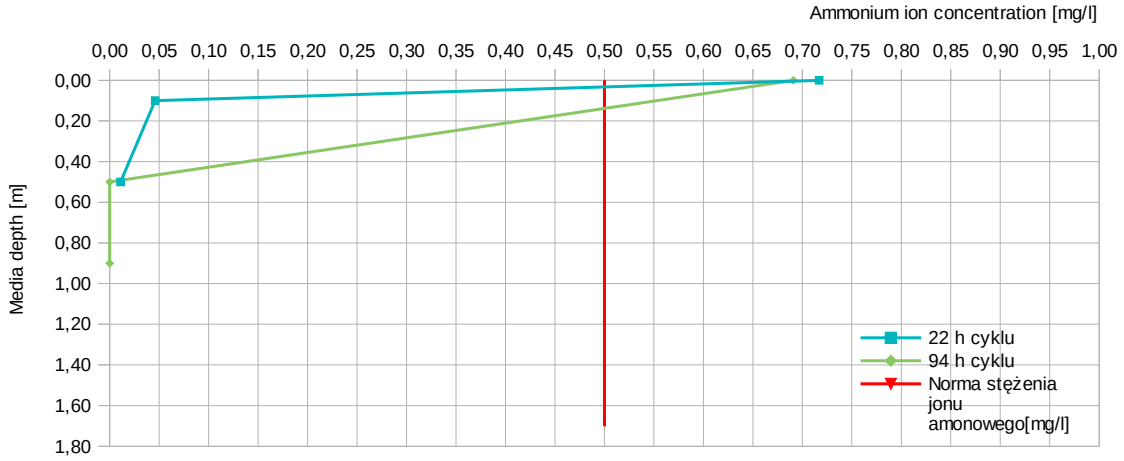


Fig.74 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 12

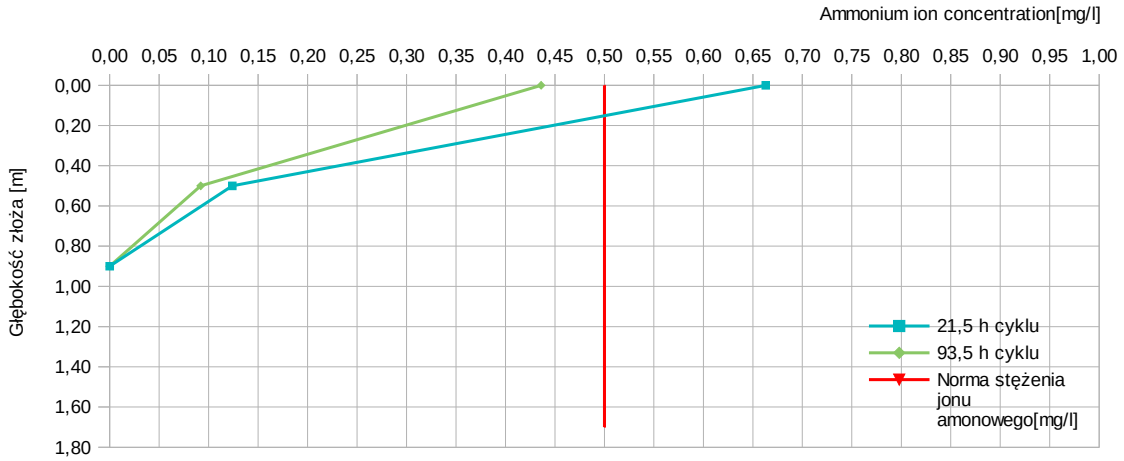


Fig. 75 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 13

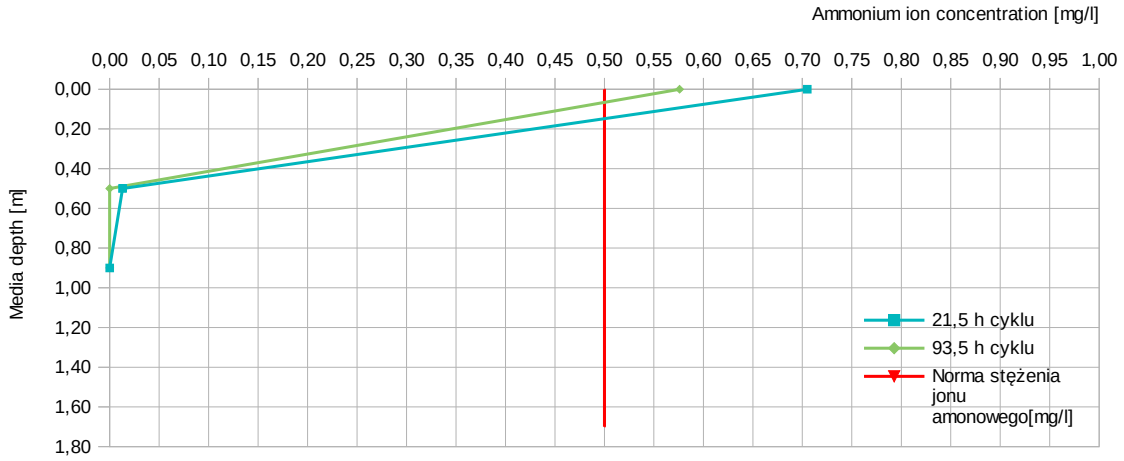


Fig.76 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 14

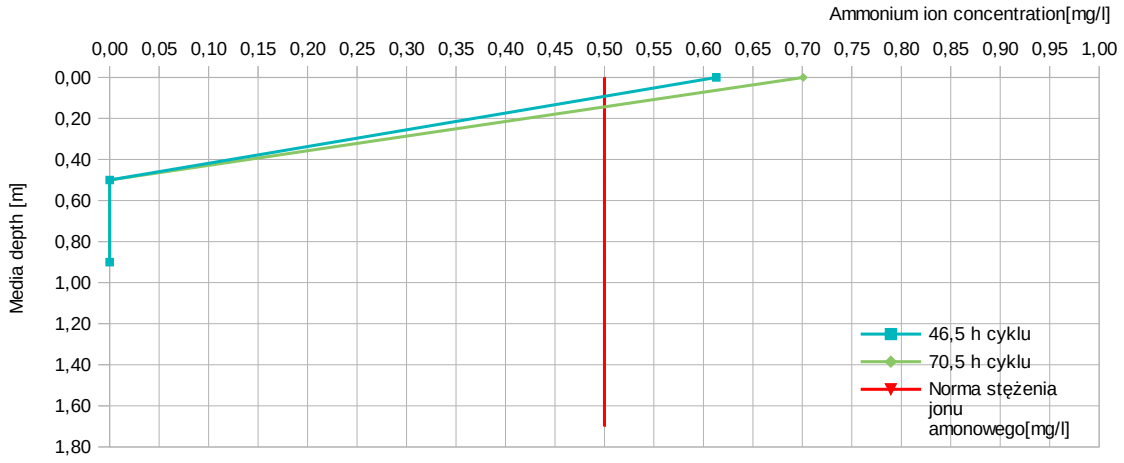


Fig. 77 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 15

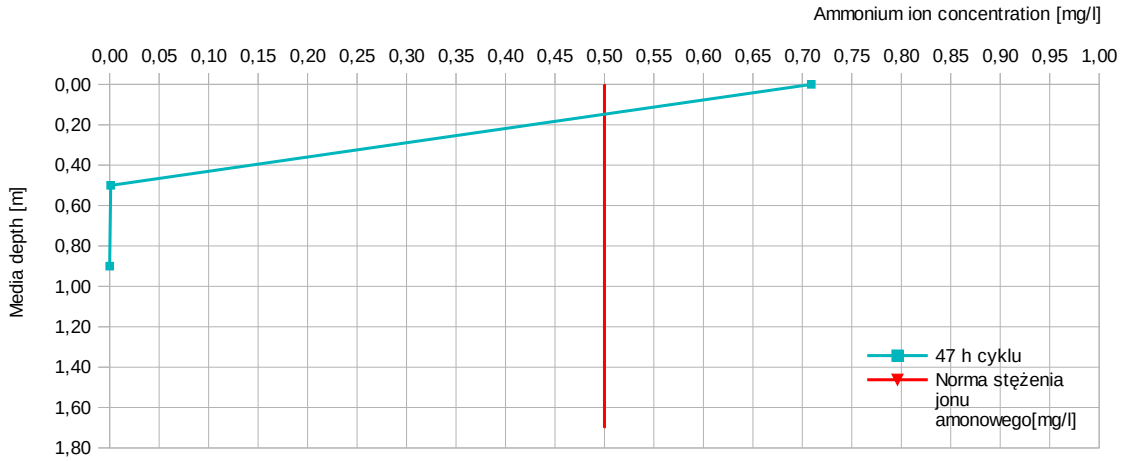
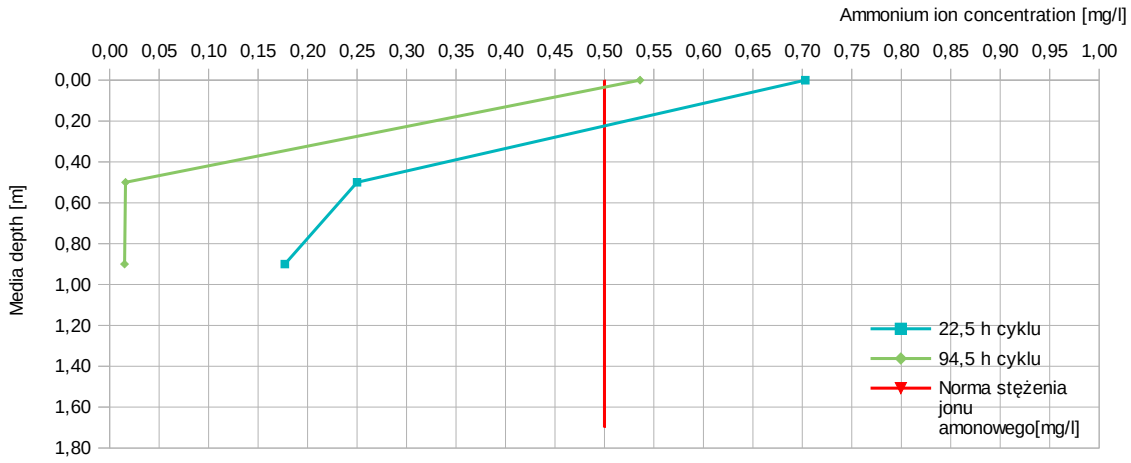


Fig. 78 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 16



4.10. Manganese removal layer (zone) for 9 m/h filtration rate

In the work-in for Mn removal period (filtration cycles 1-15) the analysis was forsaken, because no removal zone could has been identified anyway.

Upon noticing the removal effectiveness in the filtration cycle no. 16, the analysis has been conducted.

Fig. 79 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 16

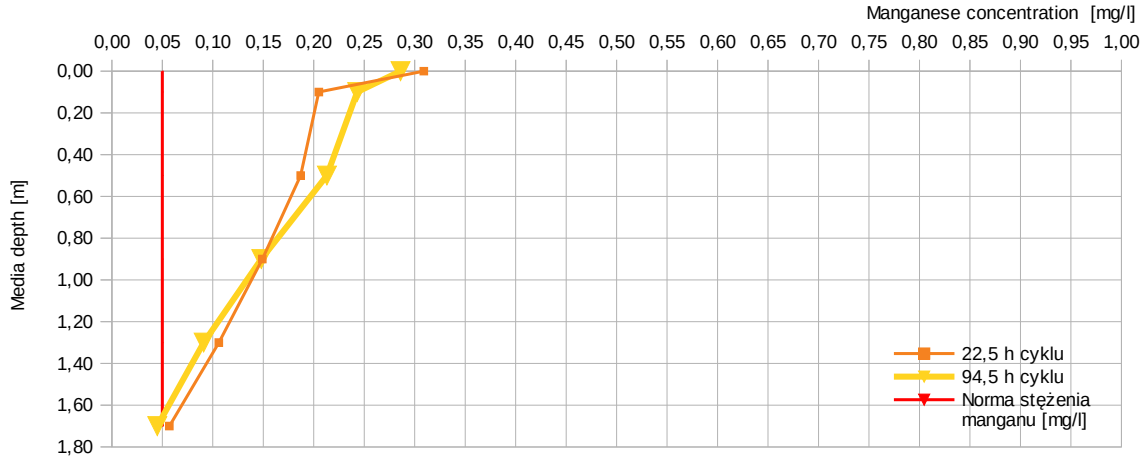


Fig. 80 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 17

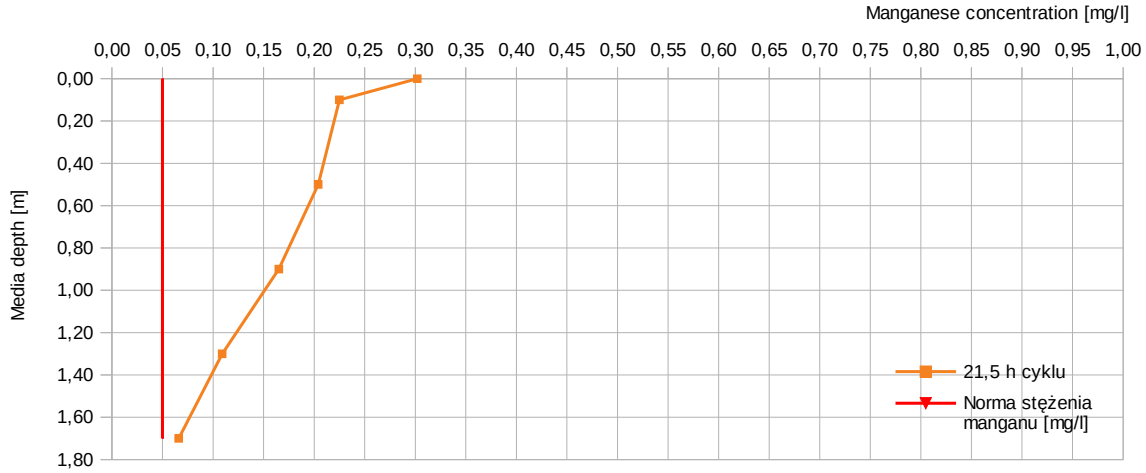


Fig. 81 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 18

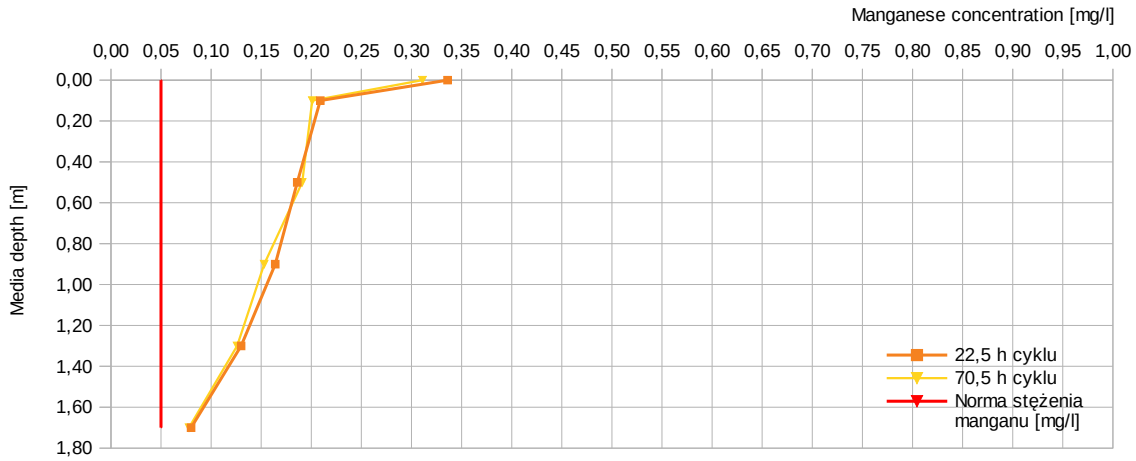


Fig. 82 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 19

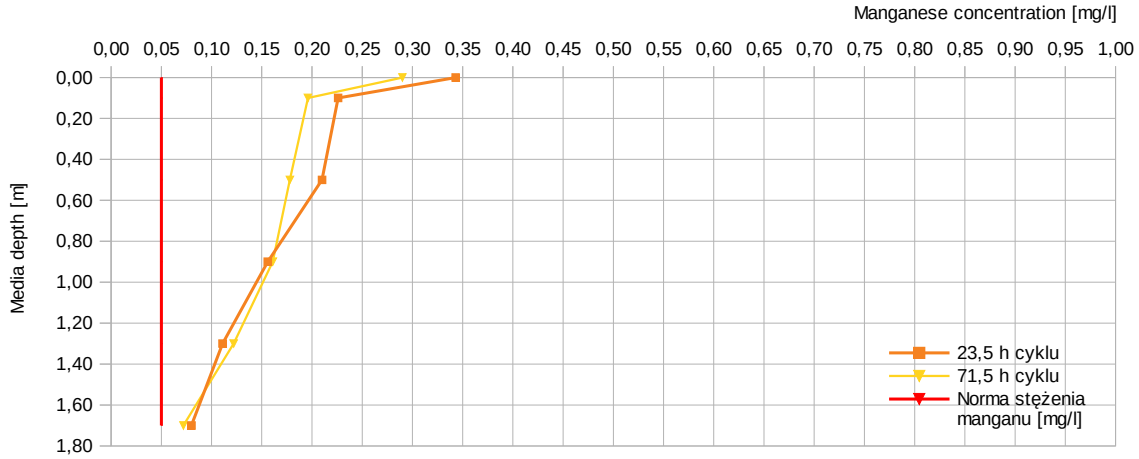
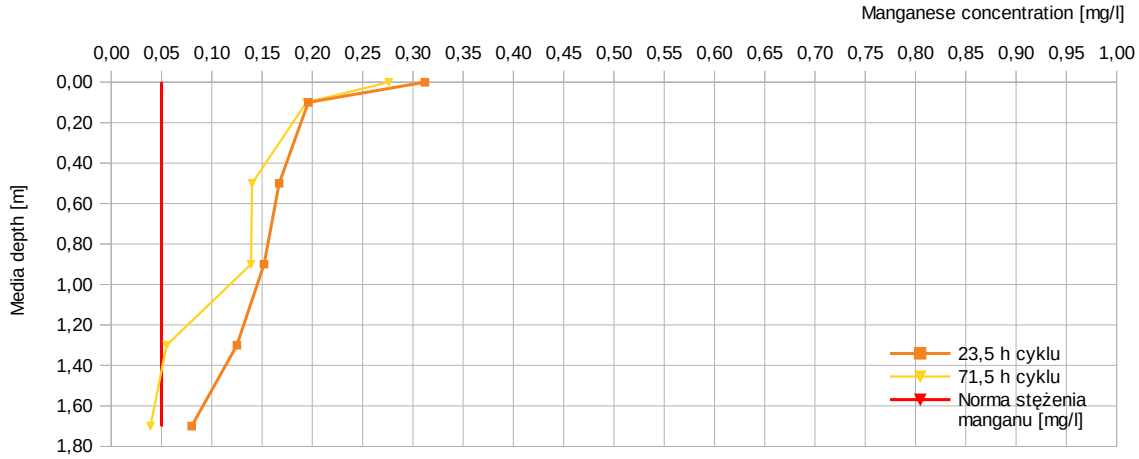
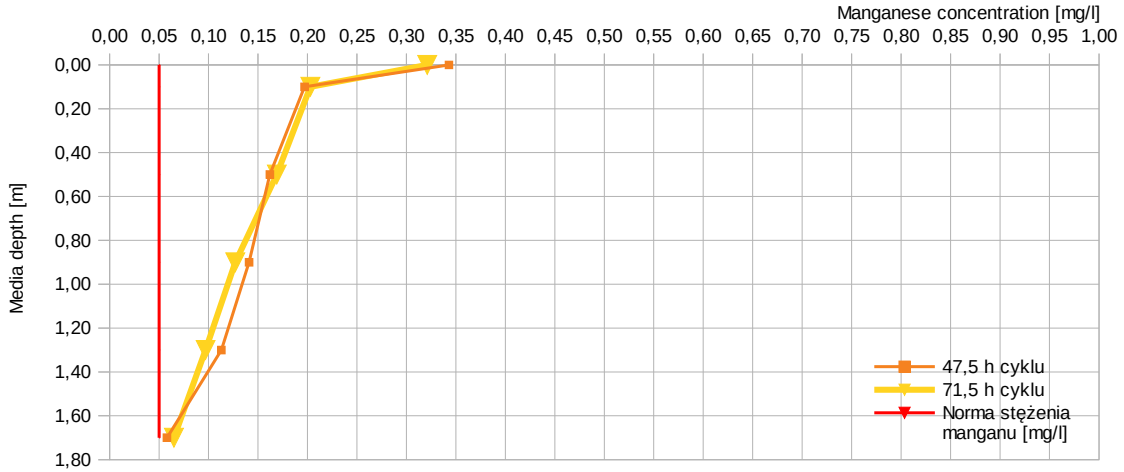


Fig. 83 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 20



Wykres 84 Manganese concentration profile (x-axis) in terms of media depth (y-axis). 9 m/h, filtration cycle no. 21



4.11. Iron removal layer (zone) for 12 m/h filtration rate

The following set of graphs shows the iron removal zone depth for every filtration cycle (16 in total).

Fig. 85 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 1

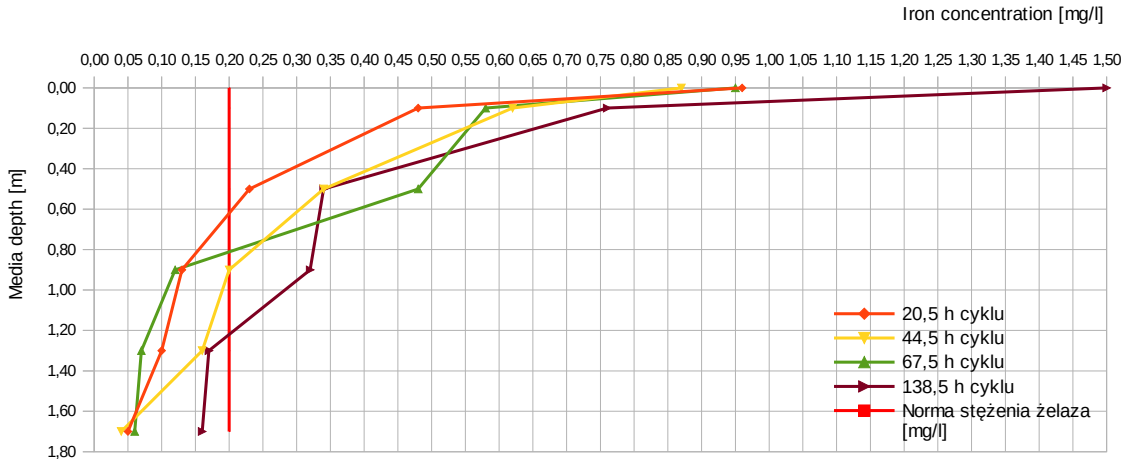


Fig. 86 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 2

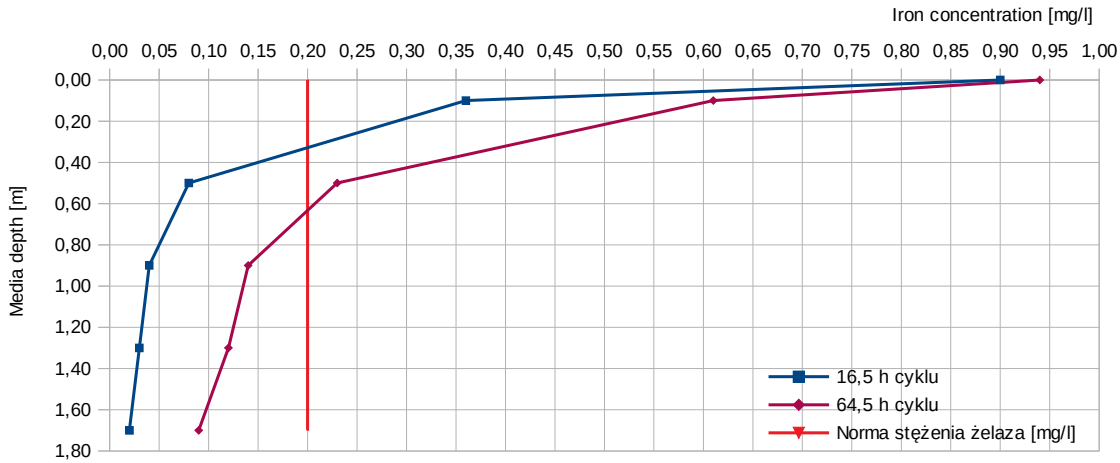


Fig. 87 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 3

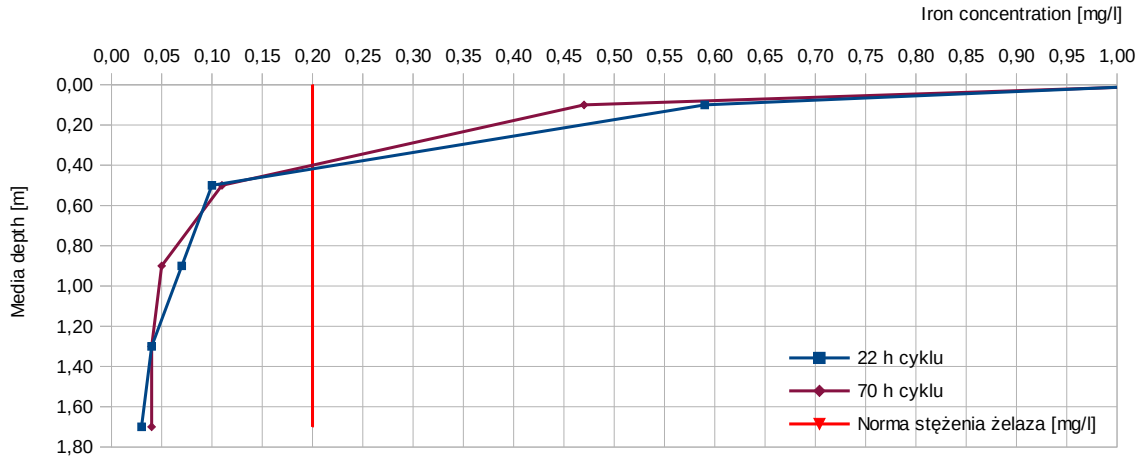


Fig. 88 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 4

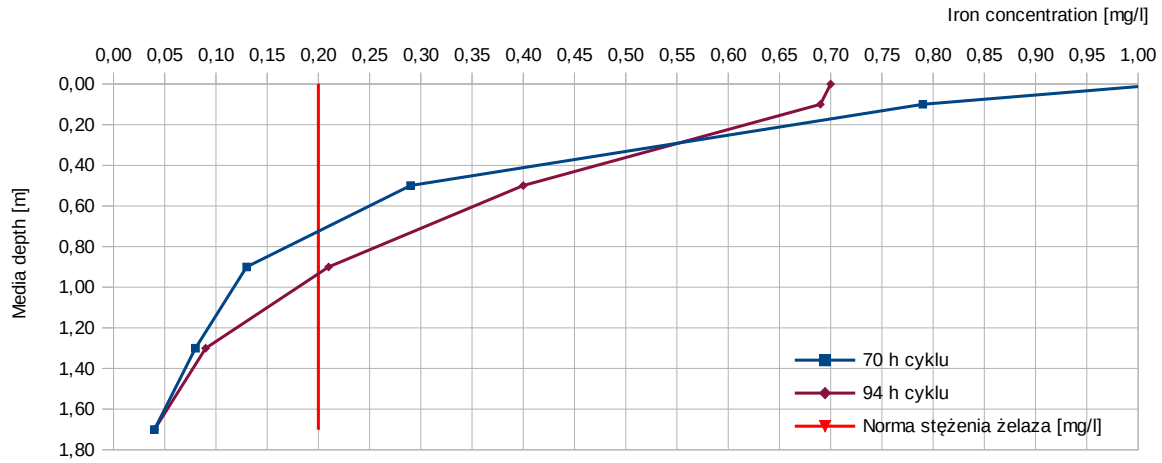


Fig. 89 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 5

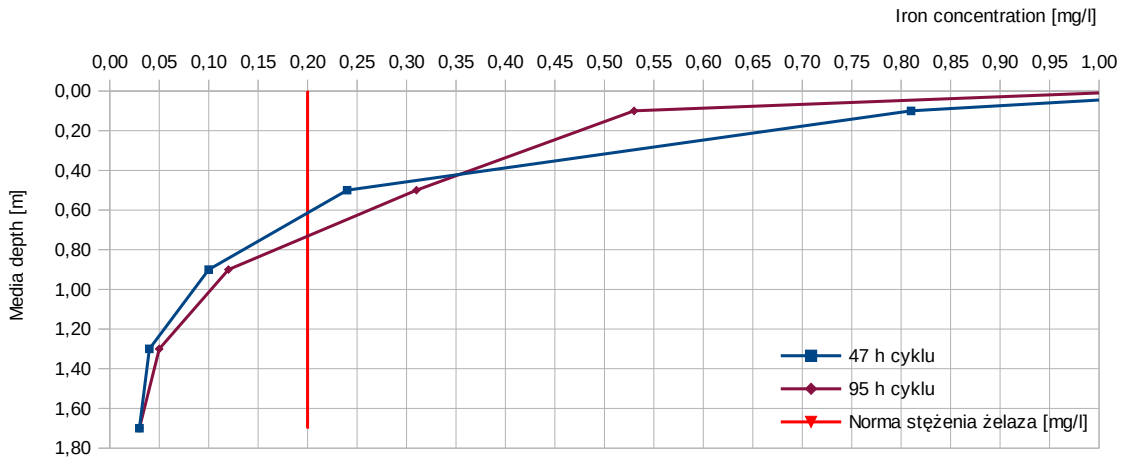


Fig. 90 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 6

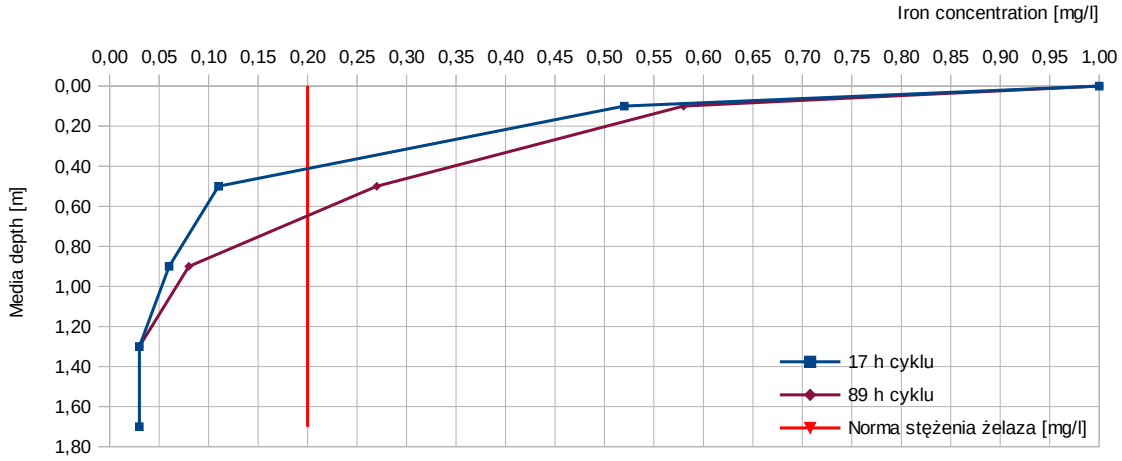


Fig. 91 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 7

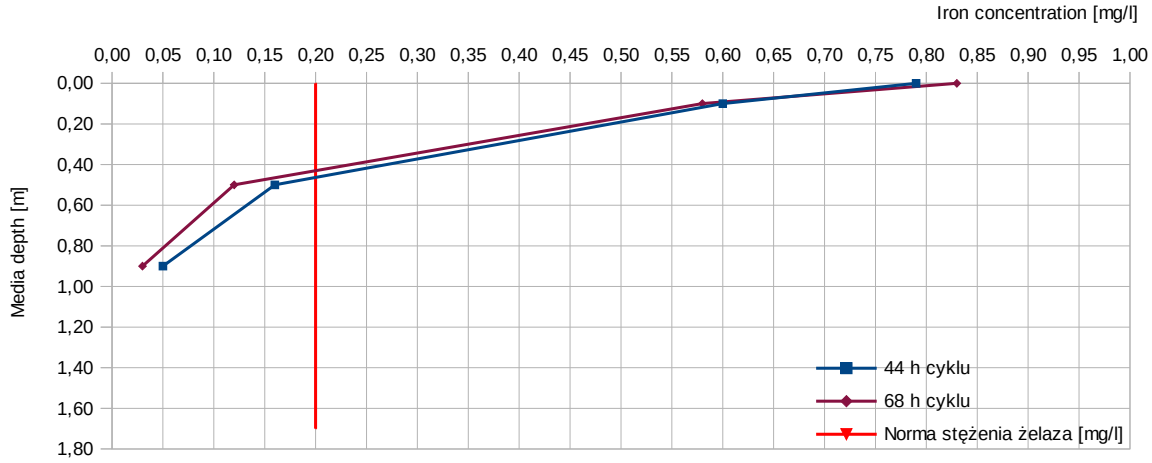


Fig. 92 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 8

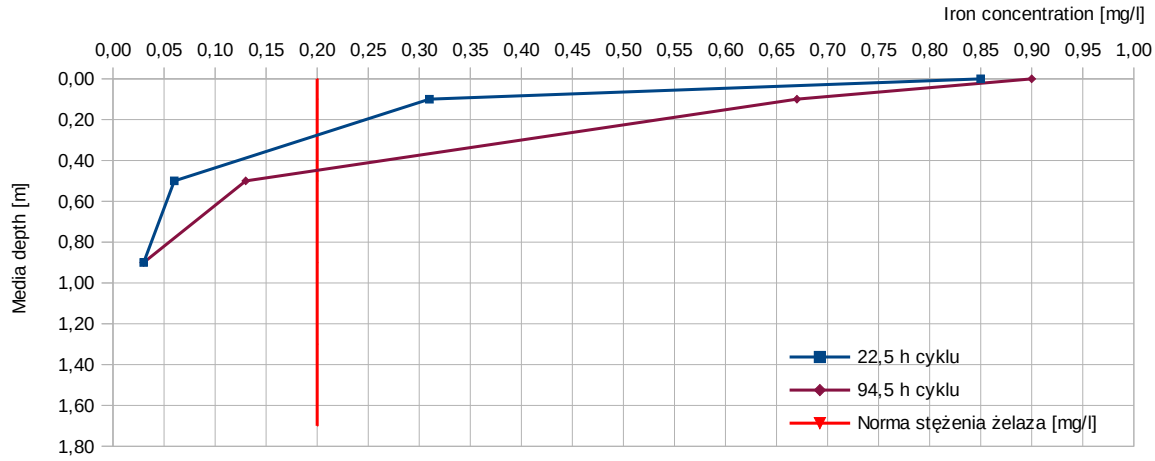


Fig. 93 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 9

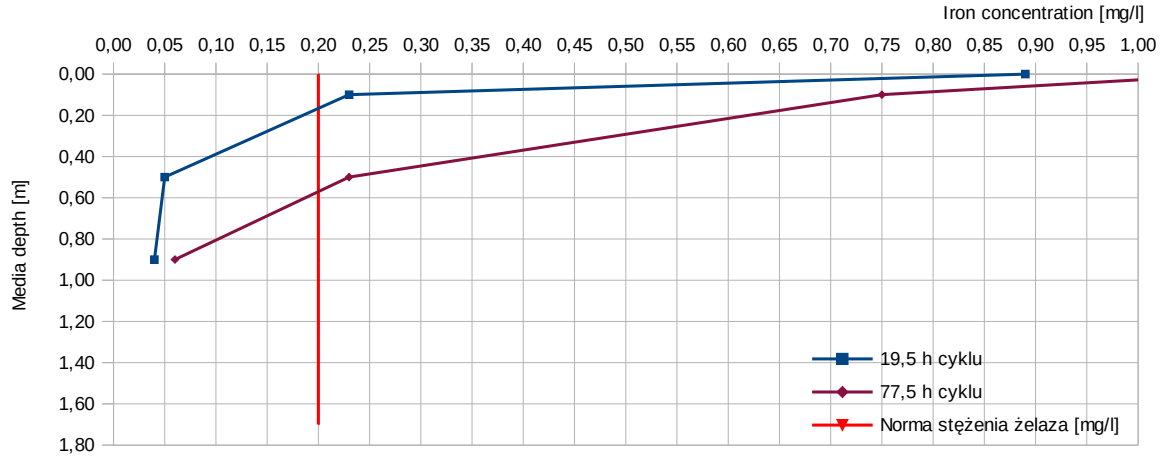


Fig. 94 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 10

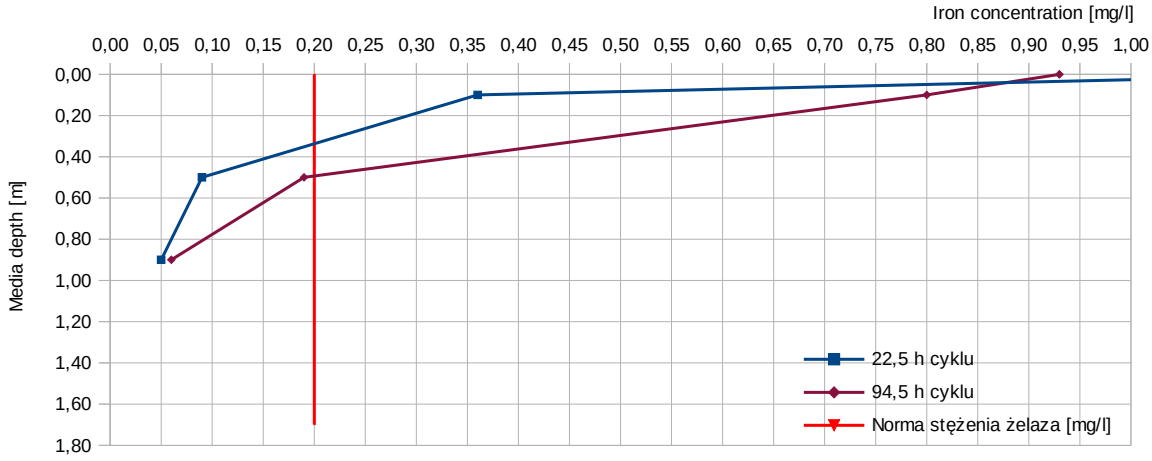


Fig. 95 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 11

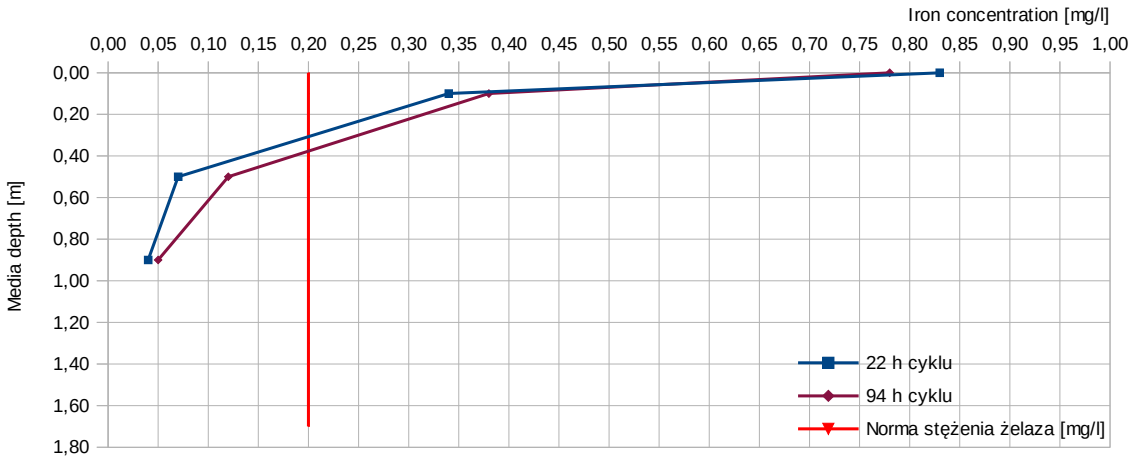


Fig. 96 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 12

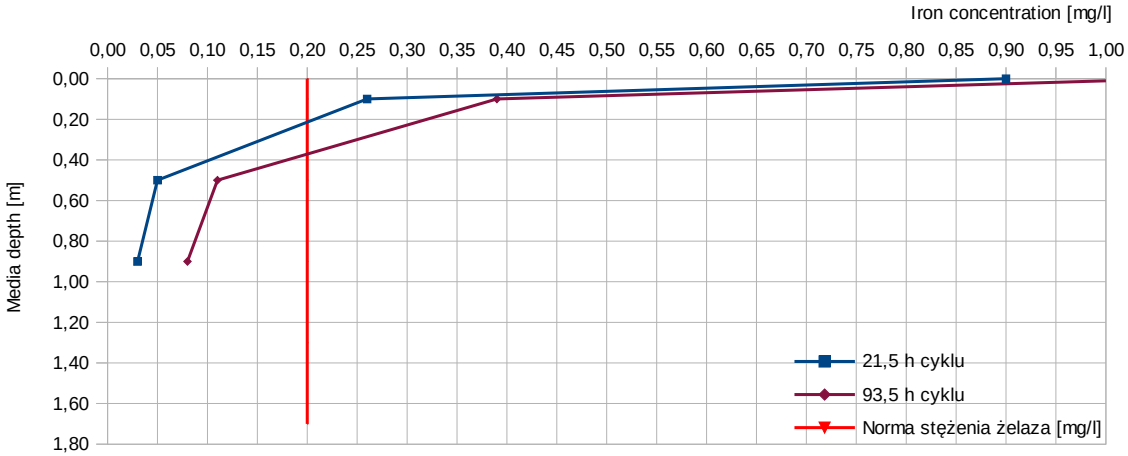
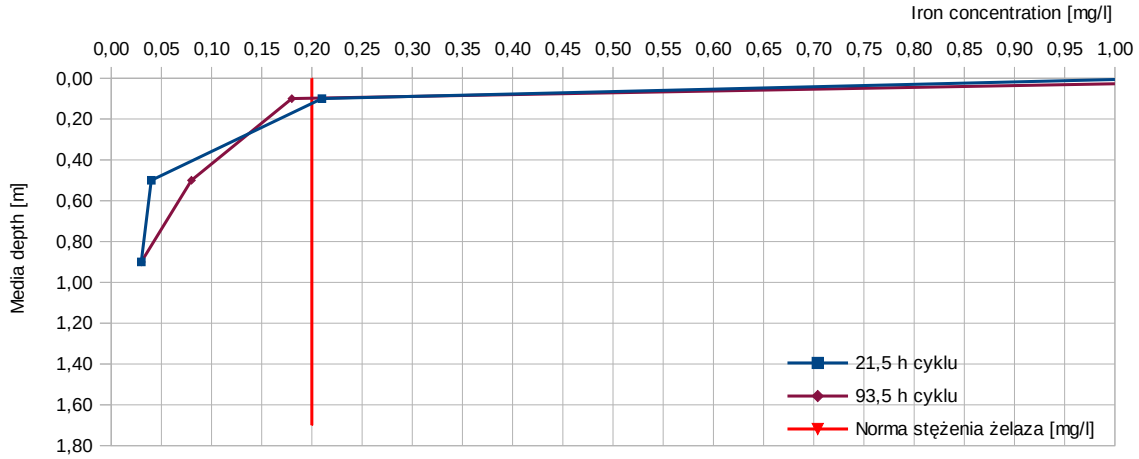


Fig. 97 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 13



Wykres 98 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 14

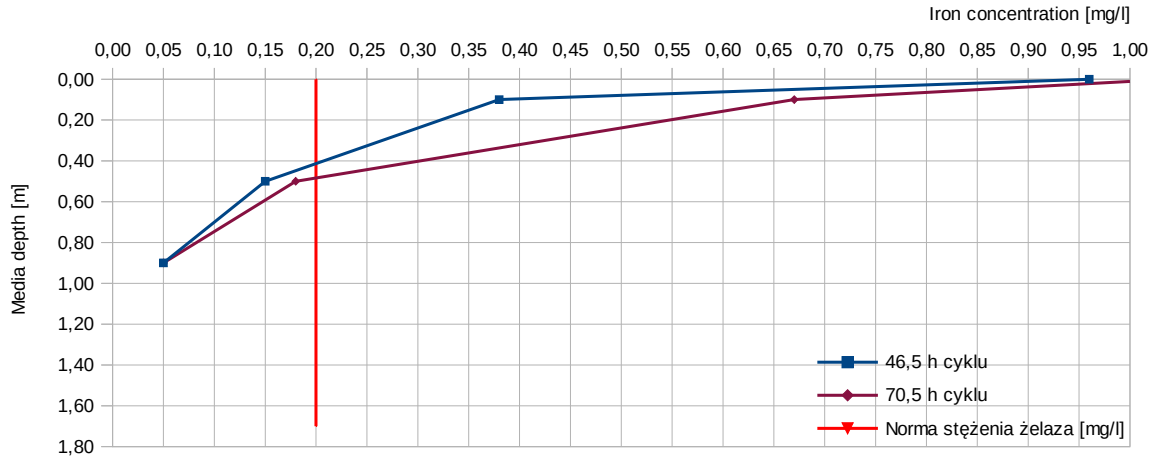


Fig. 99 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 15

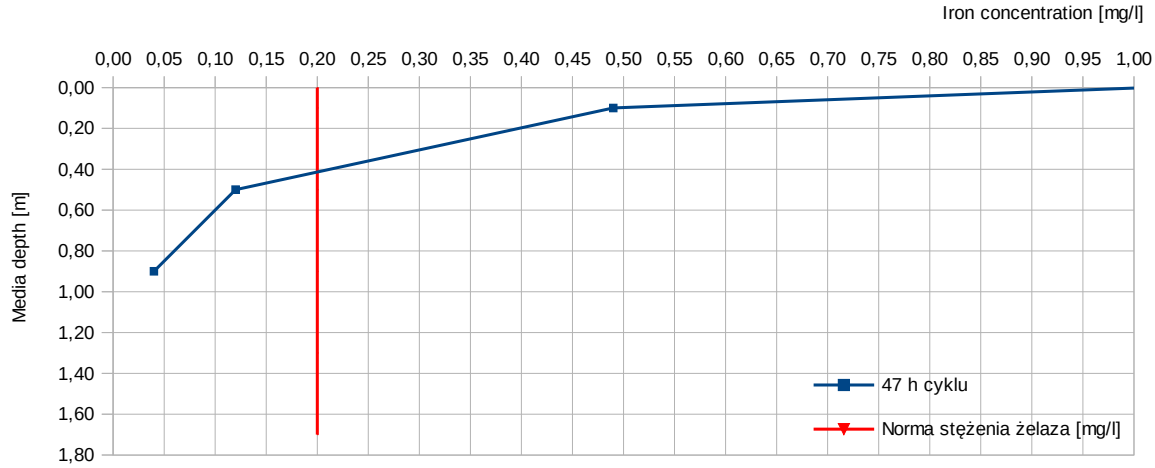
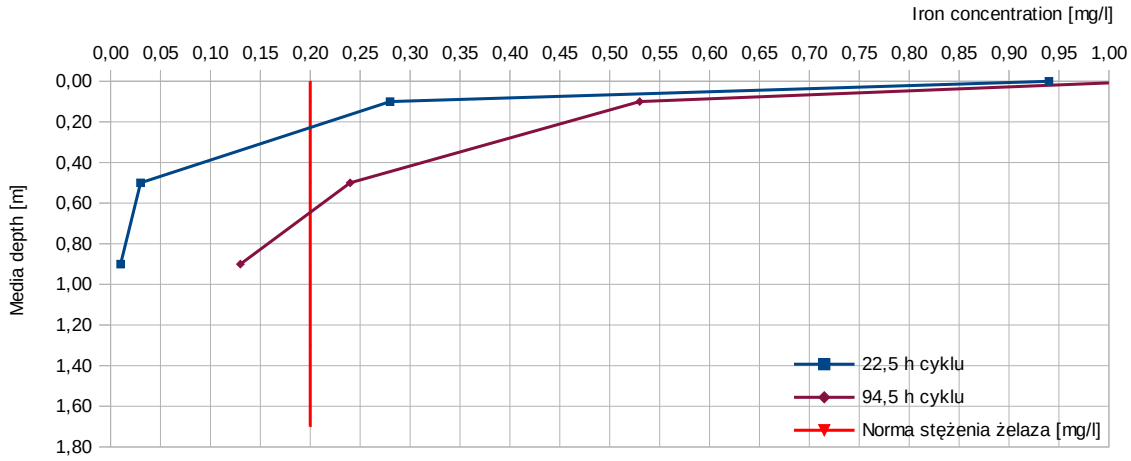


Fig. 100 Iron concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 16



4.12. Ammonium ion removal layer (zone) for 12 m/h filtration rate

In the work-in for NH^{4+} removal period (filtration cycles 1-4) the analysis was forsaken, because no removal zone could has been identified anyway.
Upon noticing the removal effectiveness in the filtration cycle no.5, the analysis has been conducted.

The following set of graphs shows the ammonium ion removal zone depth for filtration cycles 5-15.

Fig. 101 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 5

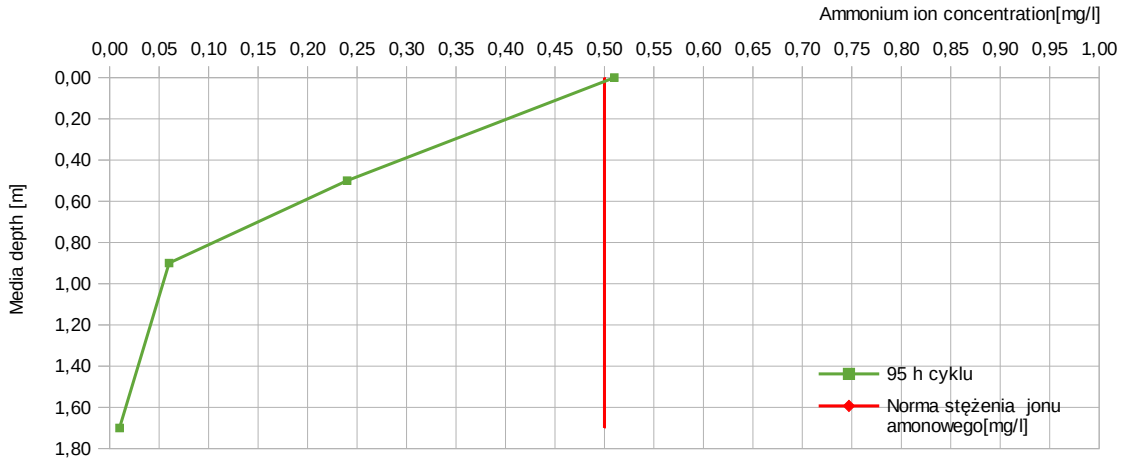


Fig. 102 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 6

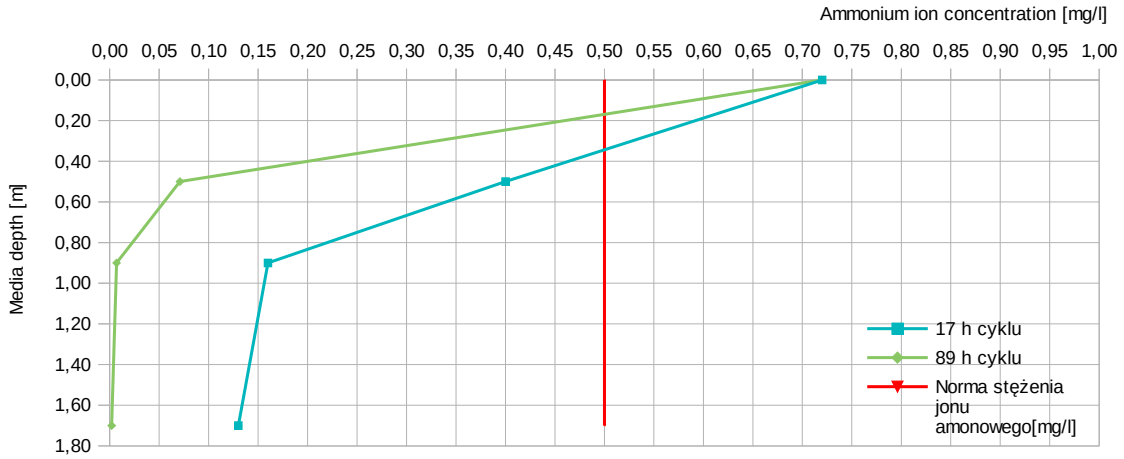


Fig. 103 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 7

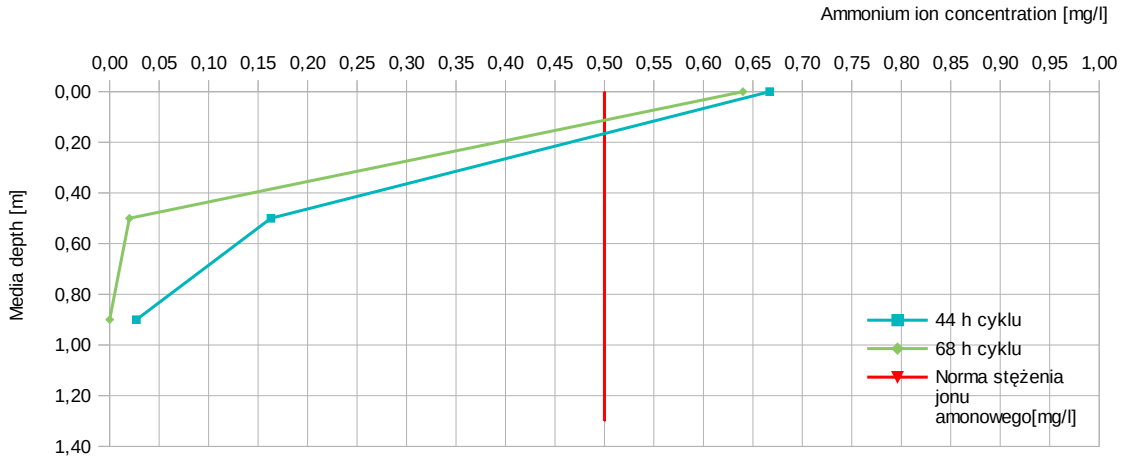


Fig. 104 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 8

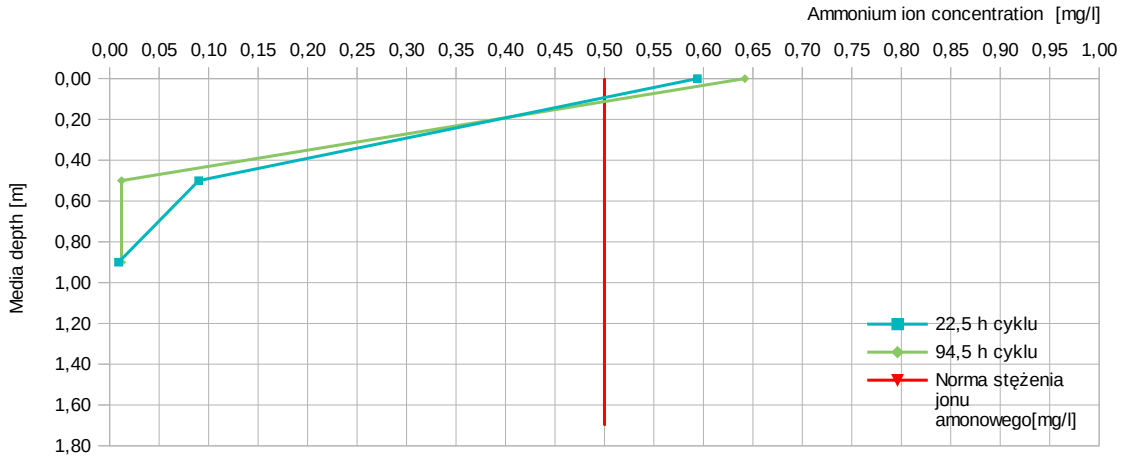


Fig. 105 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 9

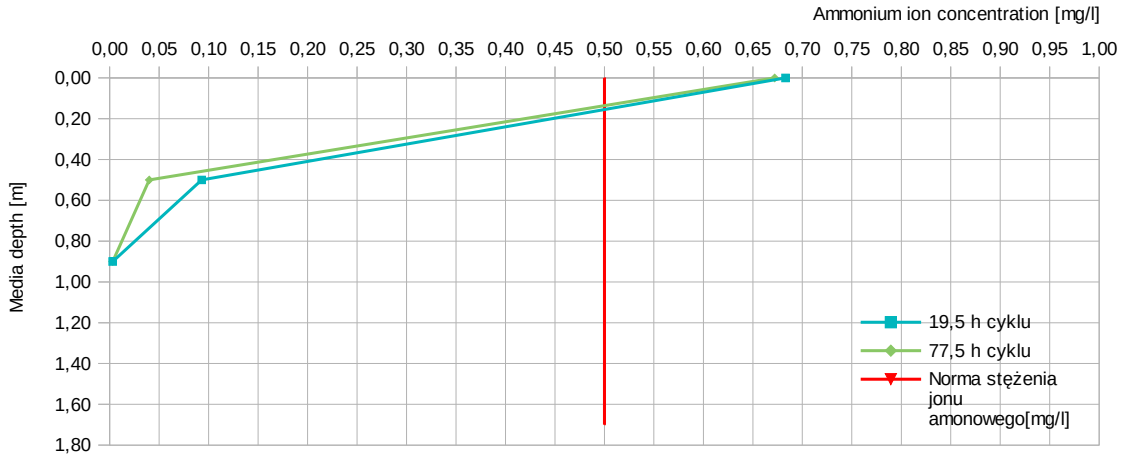


Fig. 106 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 10

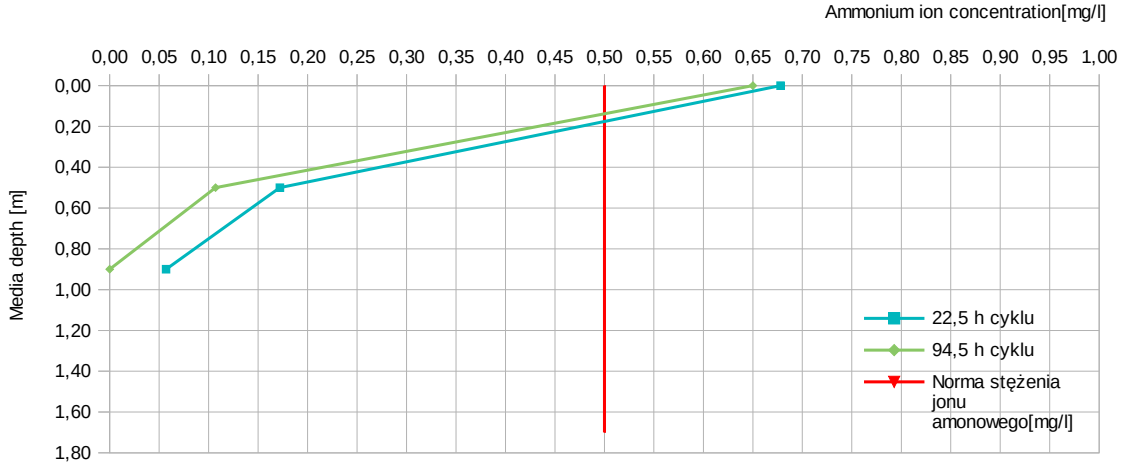


Fig. 107 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 11

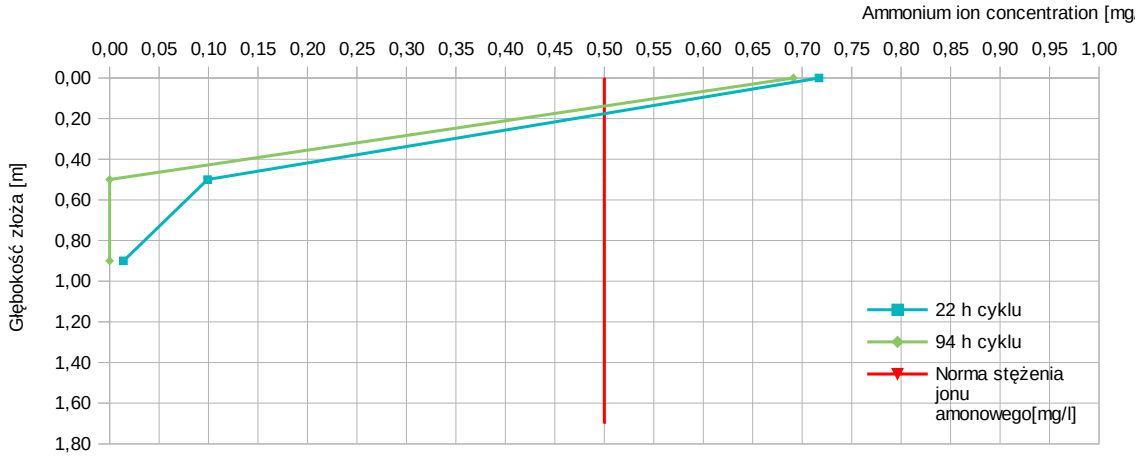


Fig. 108 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 12

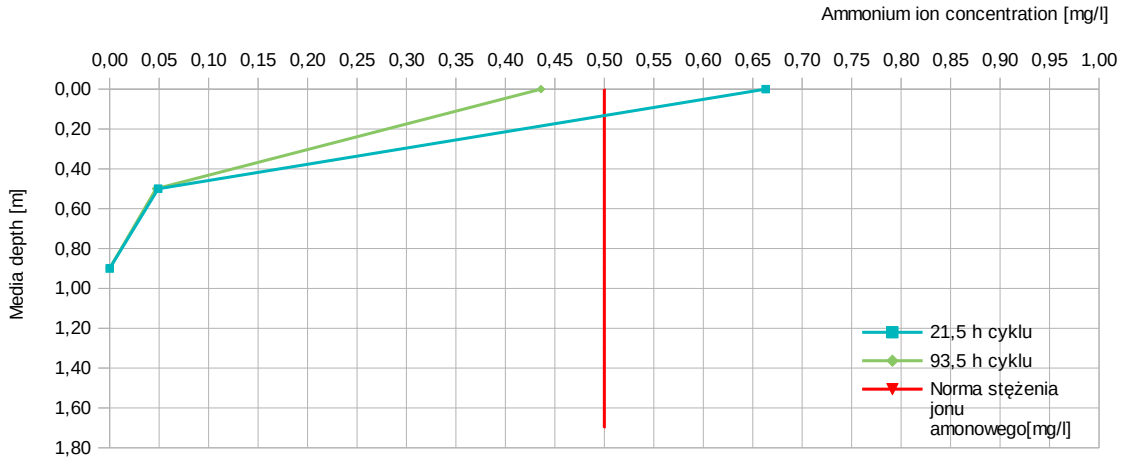


Fig. 109 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 13

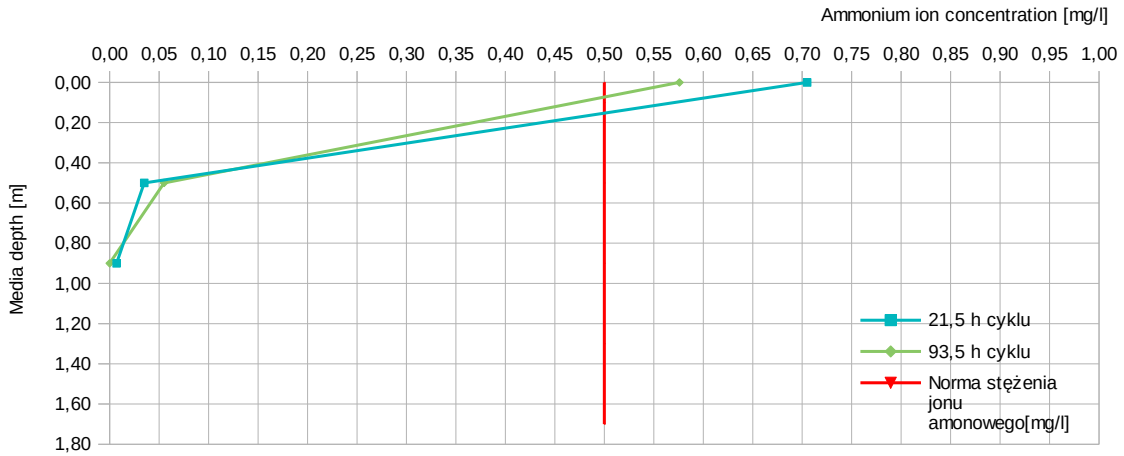


Fig. 110 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 14

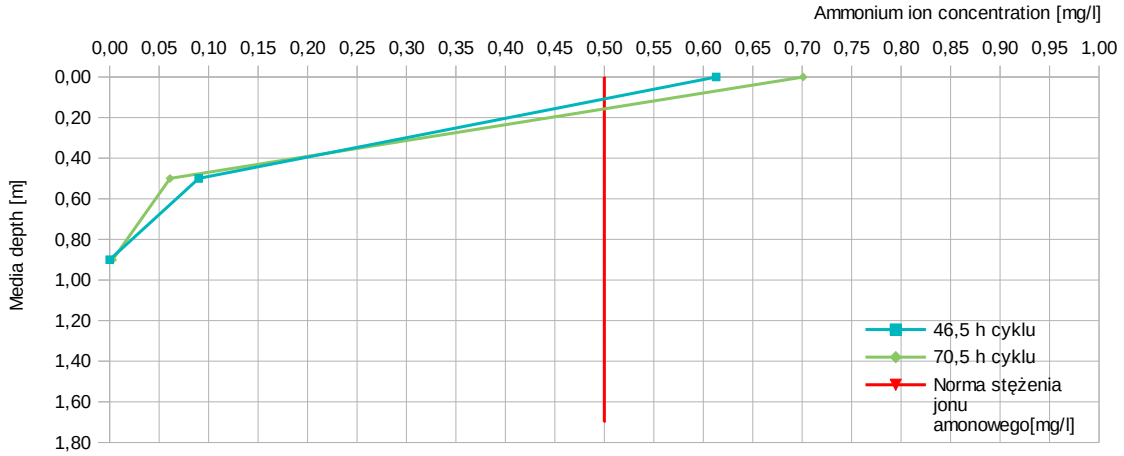


Fig. 111 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 15

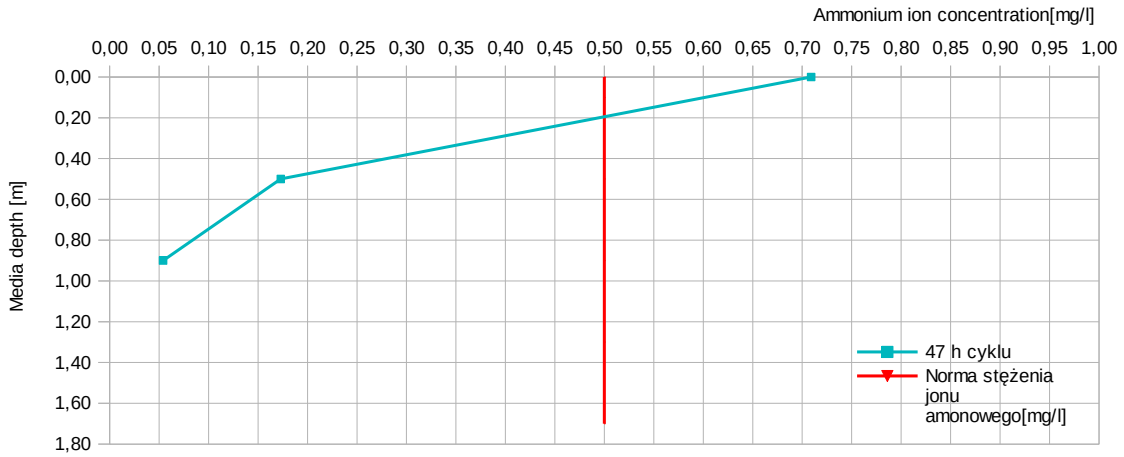
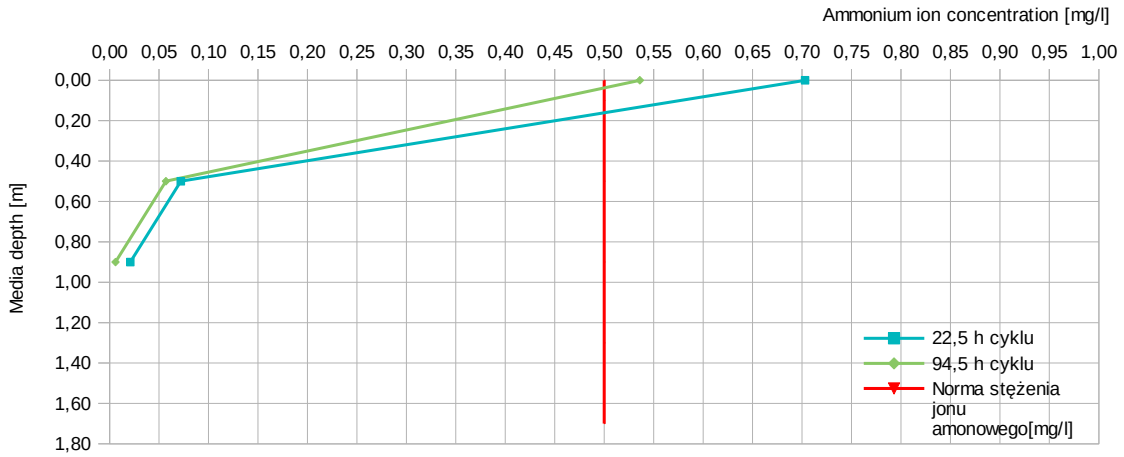


Fig. 112 Ammonium ion concentration profile (x-axis) in terms of media depth (y-axis). 12 m/h, filtration cycle no. 16



4.13. Mass capacity of Filtralite Pure HC 0,8-1,6

The data presented in the table and the chart below shows the amount of iron oxides precipitate, that has been filtered during every filtration cycle (for every filtration rate tested – 6, 9 and 12 m/h).

Tab.3 The evaluated mass capacity for Fe with respective head loss buildups in the successive filtration cycles

Filtration cycle no.	Cycle duration	Mass capacity for Fe	Head loss buildup	Filtration cycle no.	Cycle duration	Mass capacity for Fe	Head loss buildup	Filtration cycle no.	Cycle duration	Mass capacity for Fe	Head loss buildup
[-]	h	g/m²	cm H_2O	[-]	h	g/m²	cm H_2O	[-]	h	g/m²	cm H_2O
K1 – 6 m/h				K2 – 9 m/h				K3 – 12 m/h			
1	162,5	1913	54	I	162,5	2899	99	I	163	3751	126
2	161,5	1650	77	II	161,5	2424	126	II	161,5	3190	168
3	142	1613	135	III	142	2448	198	III	143	3198	273
4	118	1311	55	IV	118	1959	122	IV	118	2585	174
5	167	1954	116	V	167	2923	199	V	167	3902	258
6	165	1947	144	VI	165	2949	242	VI	165	3910	267
7	164	1947	148	VII	164	2470	194	VII	116	2291	215
8	166,5	1871	168	VIII	166,5	2798	258	VIII	101,5	1900	219
9	150,5	1728	174	IX	150,5	2595	251	IX	84,5	1713	263
10	166,5	2150	175	X	166,5	2803	260	X	94,5	2008	212
11	166	1691	126	XI	166	2516	235	XI	100,5	2242	238
12	165,5	2262	130	XII	165,5	3389	241	XII	100,5	2147	245
13	164,5	2042	120	XIII	164,5	3052	223	XIII	100,5	2904	251
14	165,5	1928	105	XIV	165,5	2876	209	XIV	101,5	2268	177
15	167	1758	148	XV	167	2633	249	XVI	47	962	100
16	170	1854	161	XVI	170	2781	240	XVI	101,5	2266	221
17	52,5	438	182	XVII	52,5	660	207	XVII	52,5	870	258
18	94,5	933	144	XVIII	94,5	1408	241	XVIII	77,5	1444	283
19	95,5	1111	171	XIX	95,5	1670	202	XIX	78,5	1780	237

Fig. 113 The evaluated mass capacity for Fe in the successive filtration cycles for 6, 9 and 12 m/h filtration rates

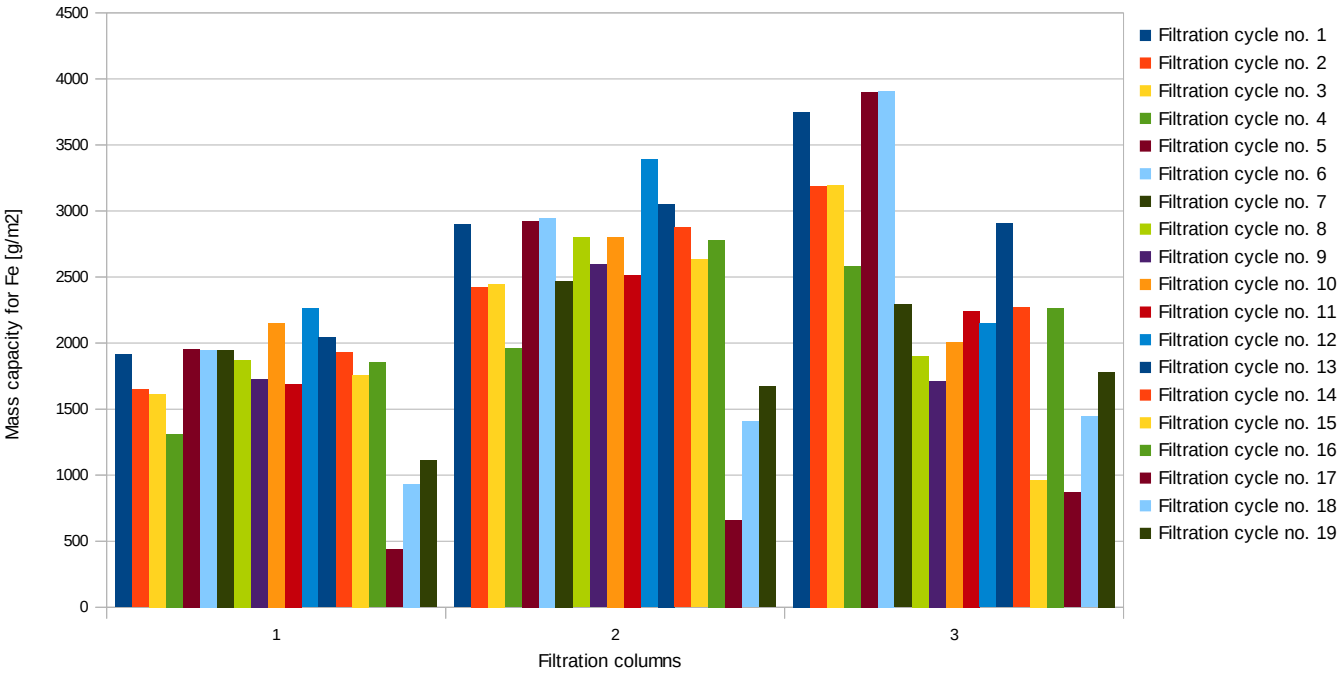
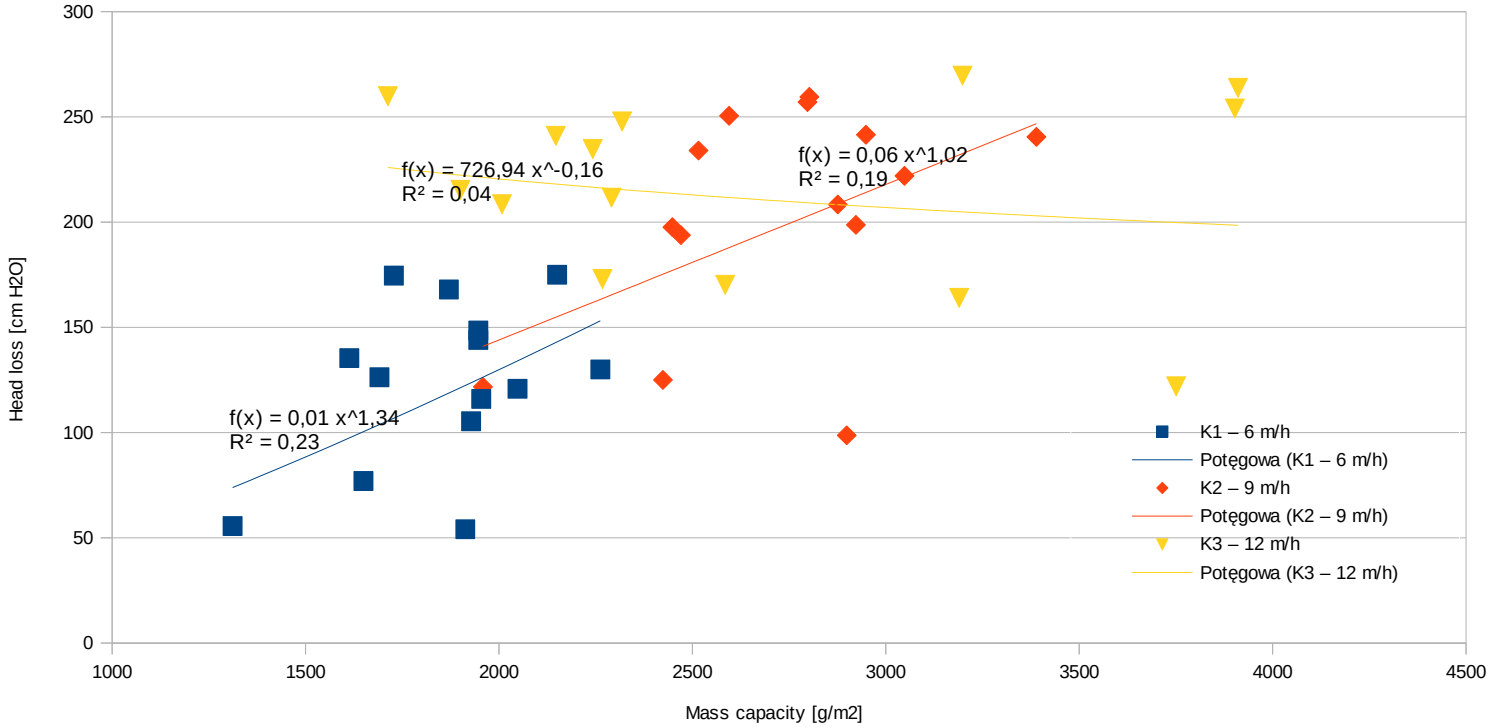


Fig. 114 The relation between the recorded head loss and respective mass capacity



4.14. The relations between head loss buildup and mass capacity

Fig. 115. The head loss buildup and respective mass capacity change in every filtration cycle for filtration rate 6 m/h

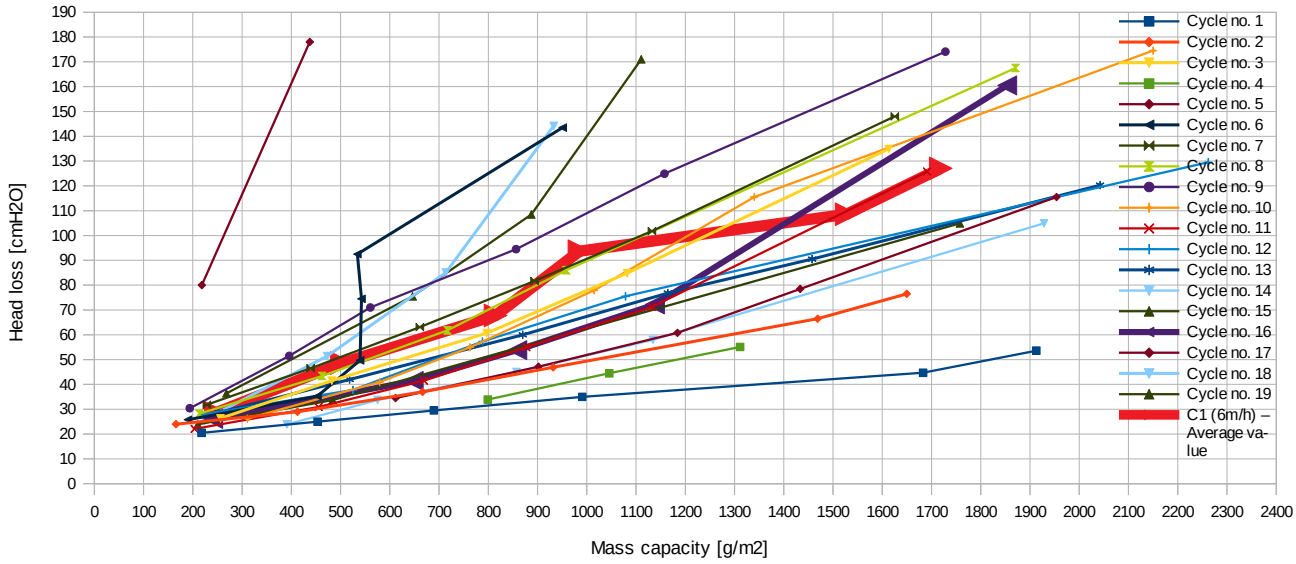


Fig. 116. The head loss buildup and respective mass capacity change in every filtration cycle for filtration rate 9 m/h

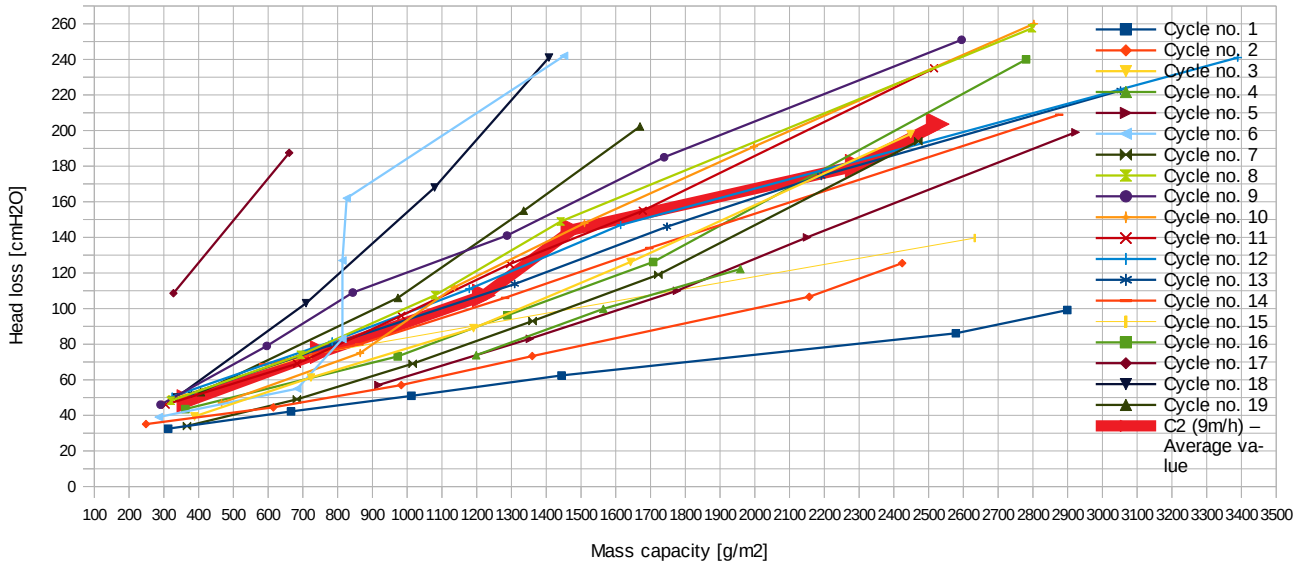
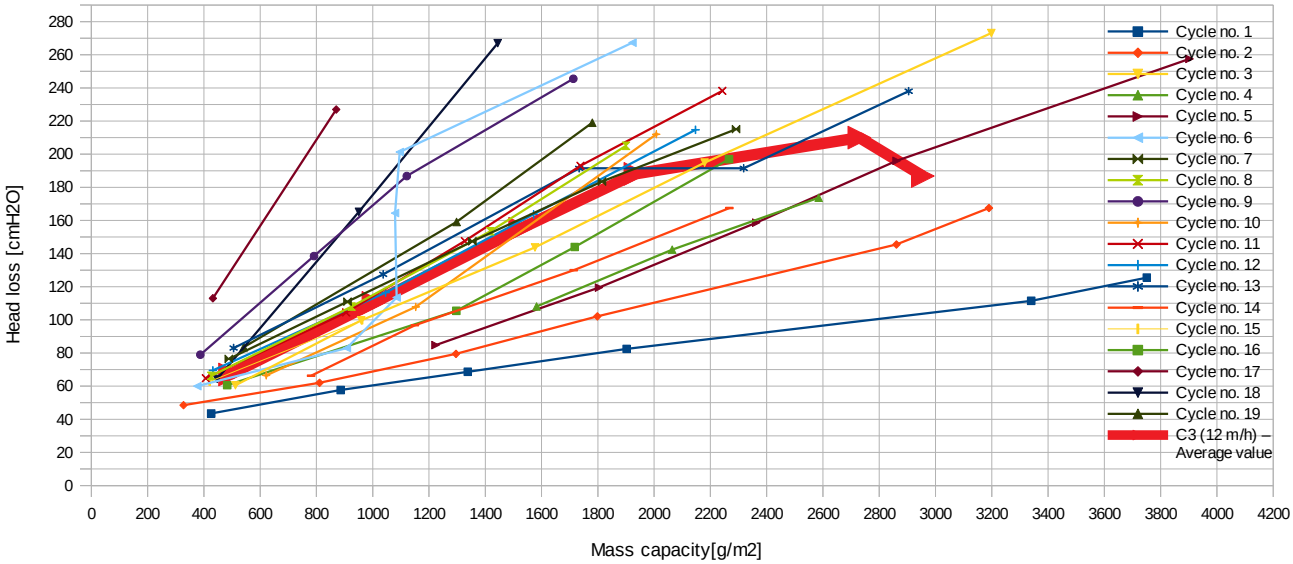


Fig. 117. The head loss buildup and respective mass capacity change in every filtration cycle for filtration rate 12 m/h



4.15. Head loss at consecutive media depths analysis for filtration rate 6, 9 and 12 m/h

In this section the head loss profile changes have been presented for selected filtration cycles. If the head loss curve crosses the y-axis it indicates the underpressure. The moment of underpressure occurrence is potentially problematic for the treatment process quality, because it may cause striping of contaminants settled in the media (so they pass the filter). The risk of underpressure occurrence can be compensated with sufficiently high freeboard, which height can be estimated form the graphs presented below.

Fig. 118 Head loss at consecutive media depths in the filtration cycle no. 1 for filtration rate 6 m/h

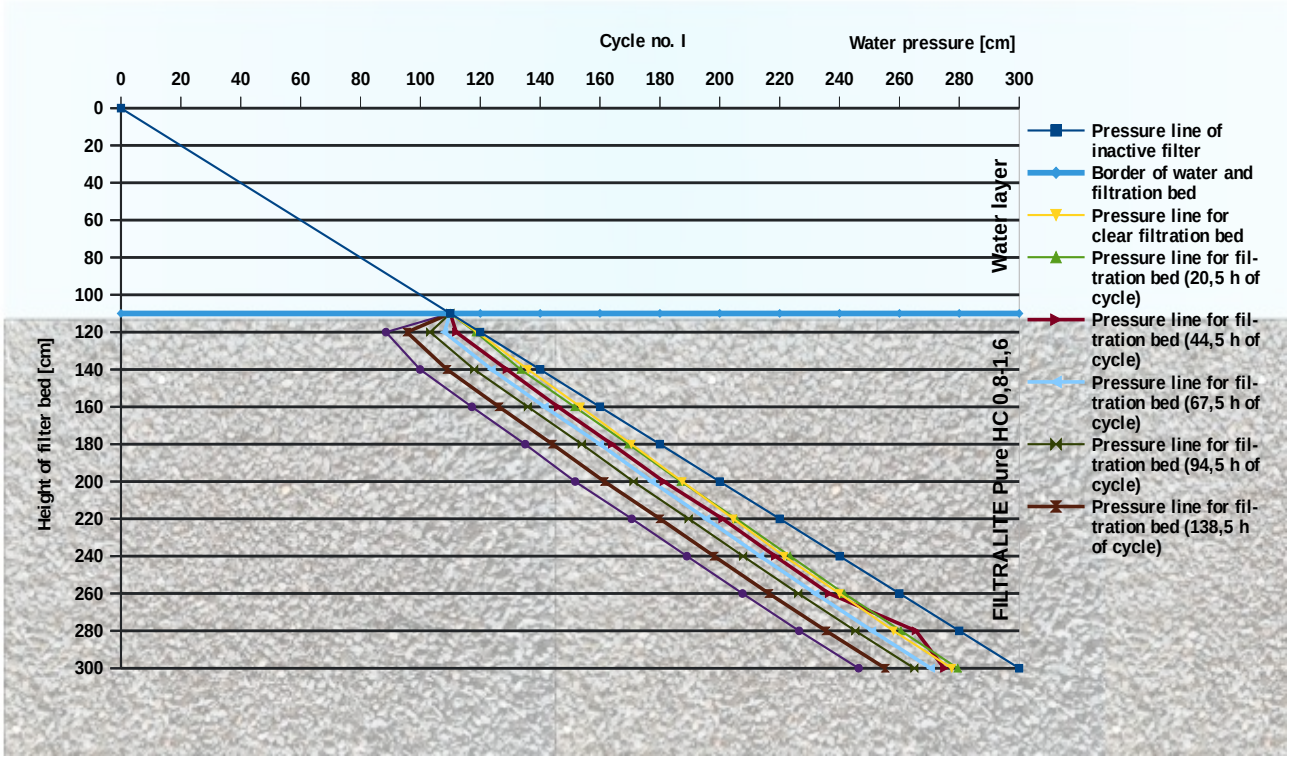


Fig. 119 Head loss at consecutive media depths in the filtration cycle no. 8 for filtration rate 6 m/h

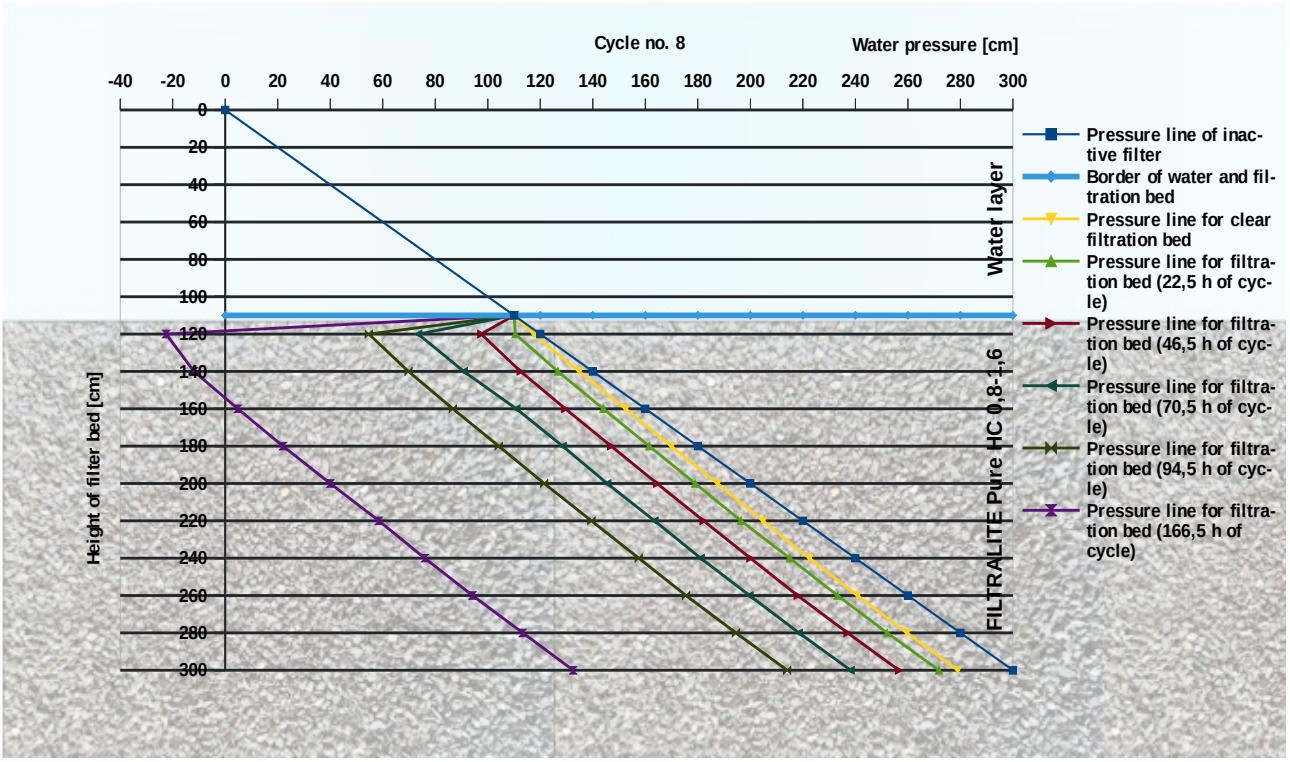


Fig 120 Head loss at consecutive media depths in the filtration cycle no. 16 for filtration rate 6 m/h

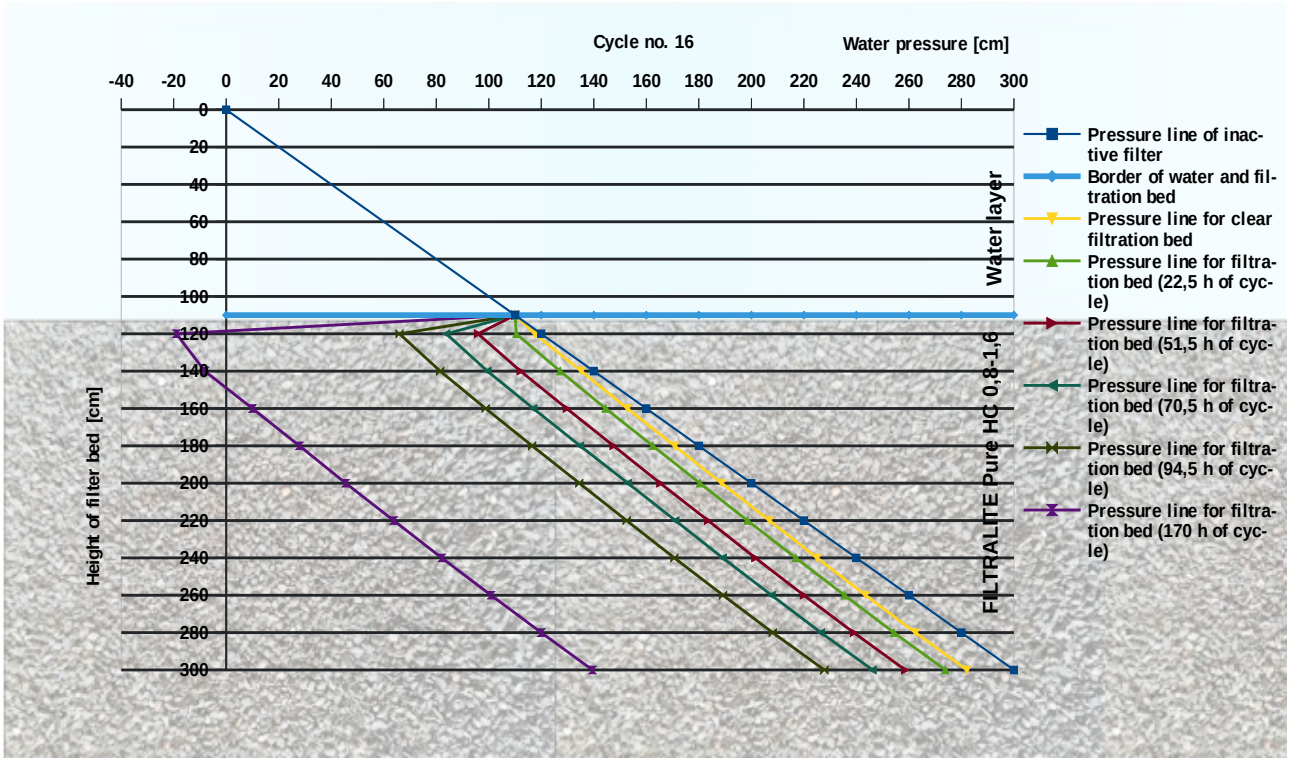


Fig. 121 Head loss at consecutive media depths in the filtration cycle no. 19 for filtration rate 6 m/h

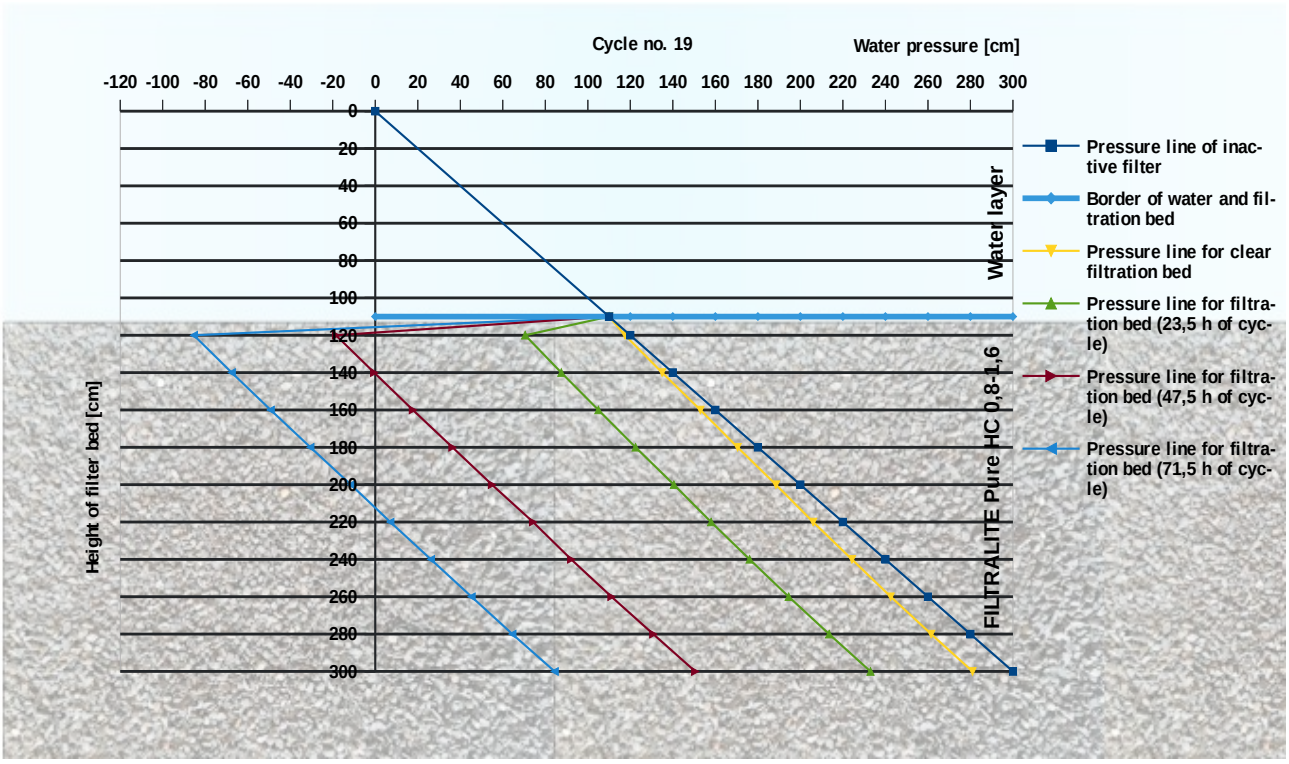


Fig. 122 Head loss at consecutive media depths in the filtration cycle no. 20 for filtration rate 6 m/h

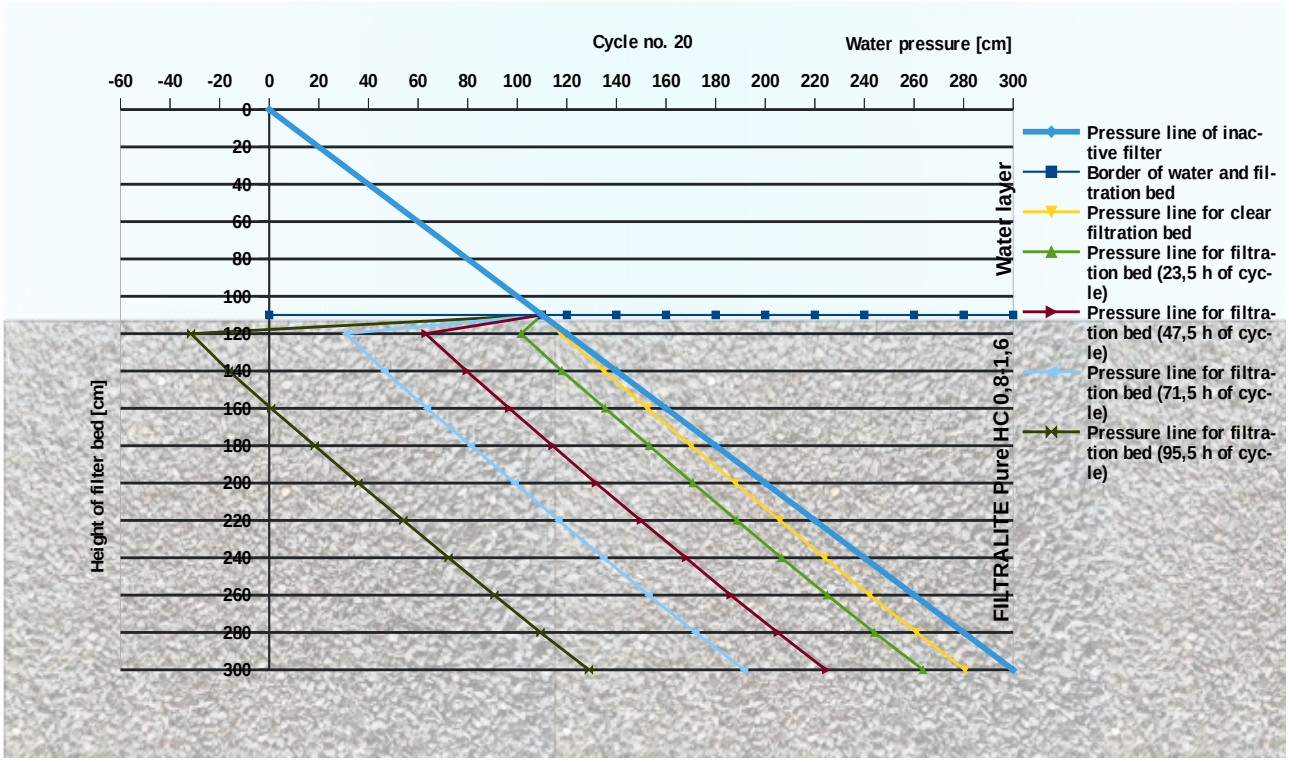


Fig. 123.Head loss at consecutive media depths in the filtration cycle no. 1 for filtration rate 9 m/h

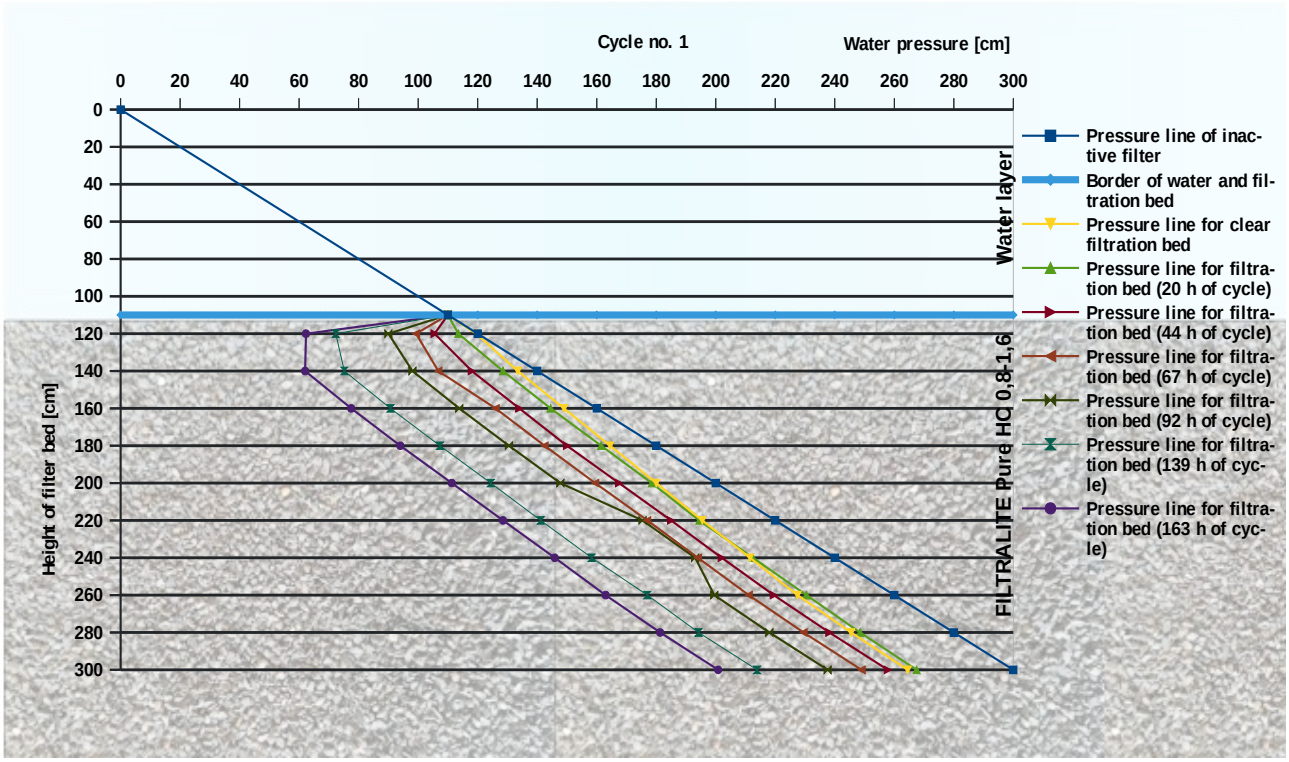


Fig. 124 Head loss at consecutive media depths in the filtration cycle no. 8 for filtration rate 9 m/h

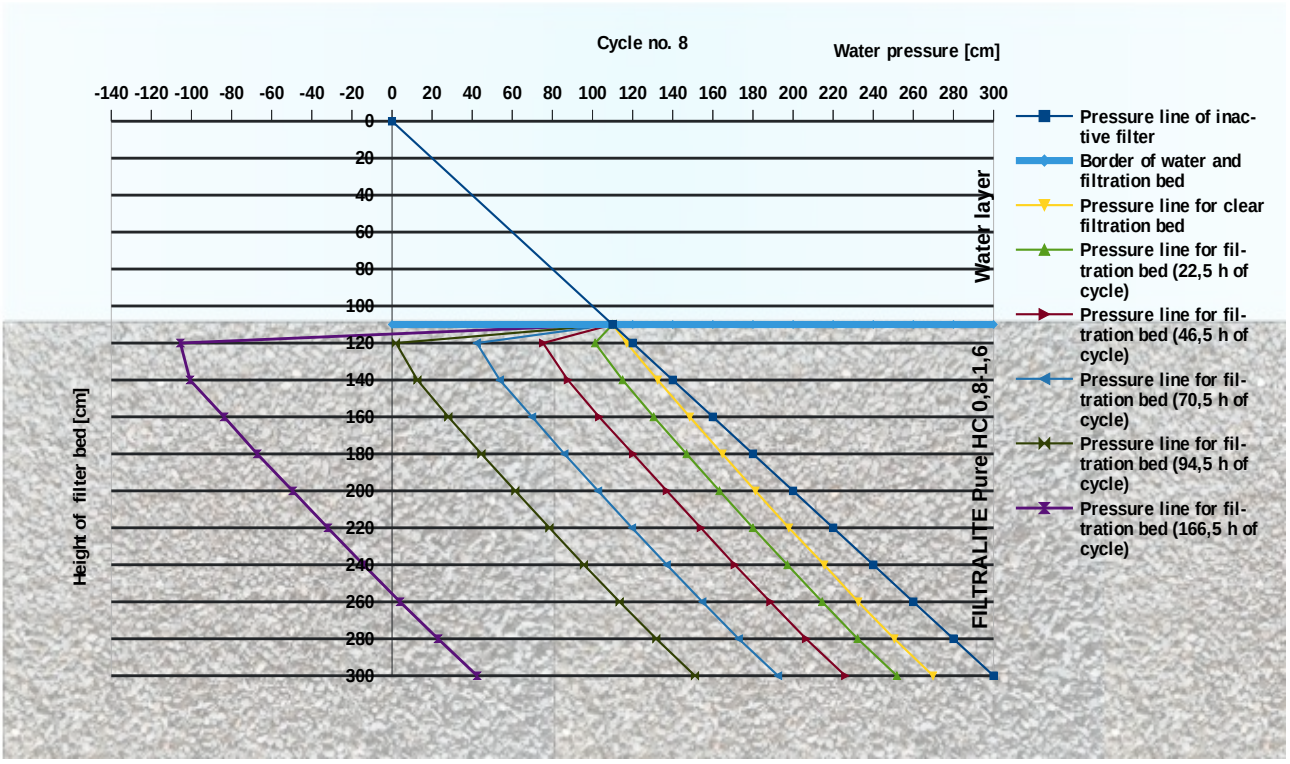


Fig. 125 Head loss at consecutive media depths in the filtration cycle no. 16 for filtration rate 9 m/h

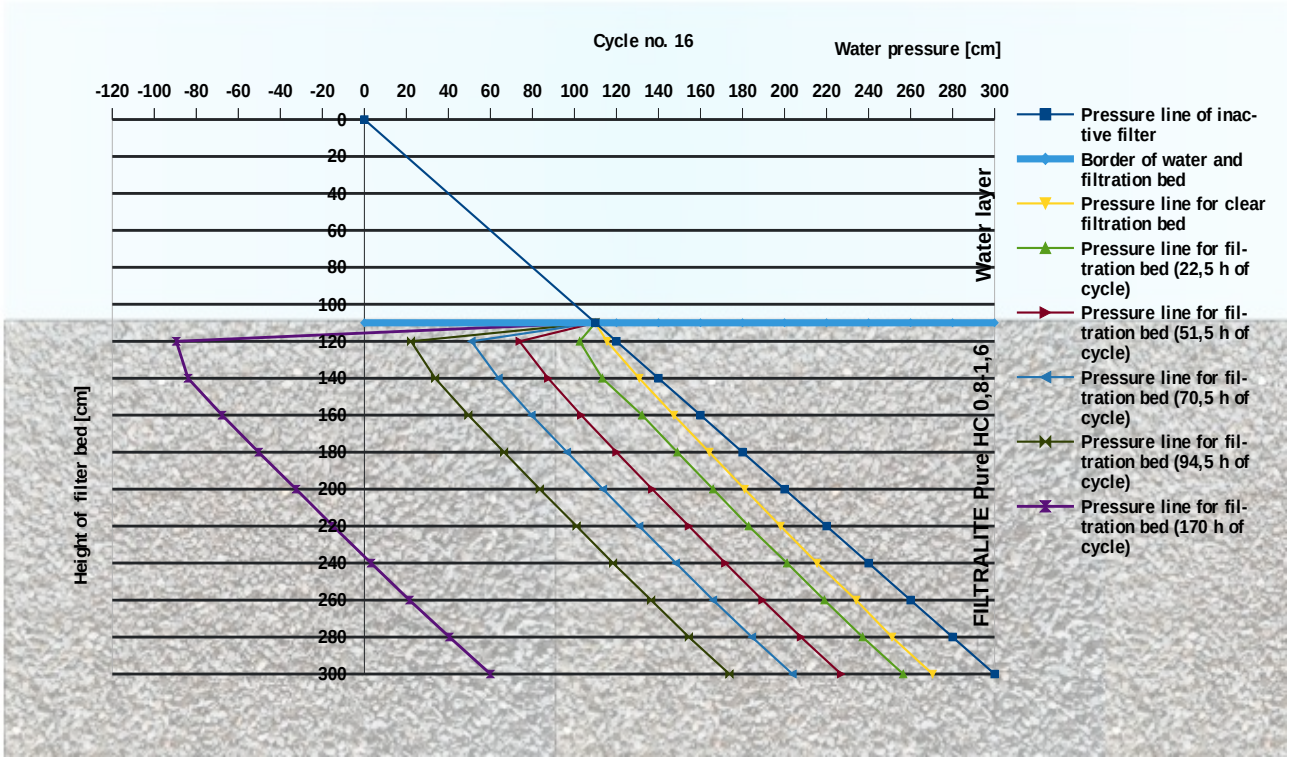


Fig. 126 Head loss at consecutive media depths in the filtration cycle no. 19 for filtration rate 9 m/h

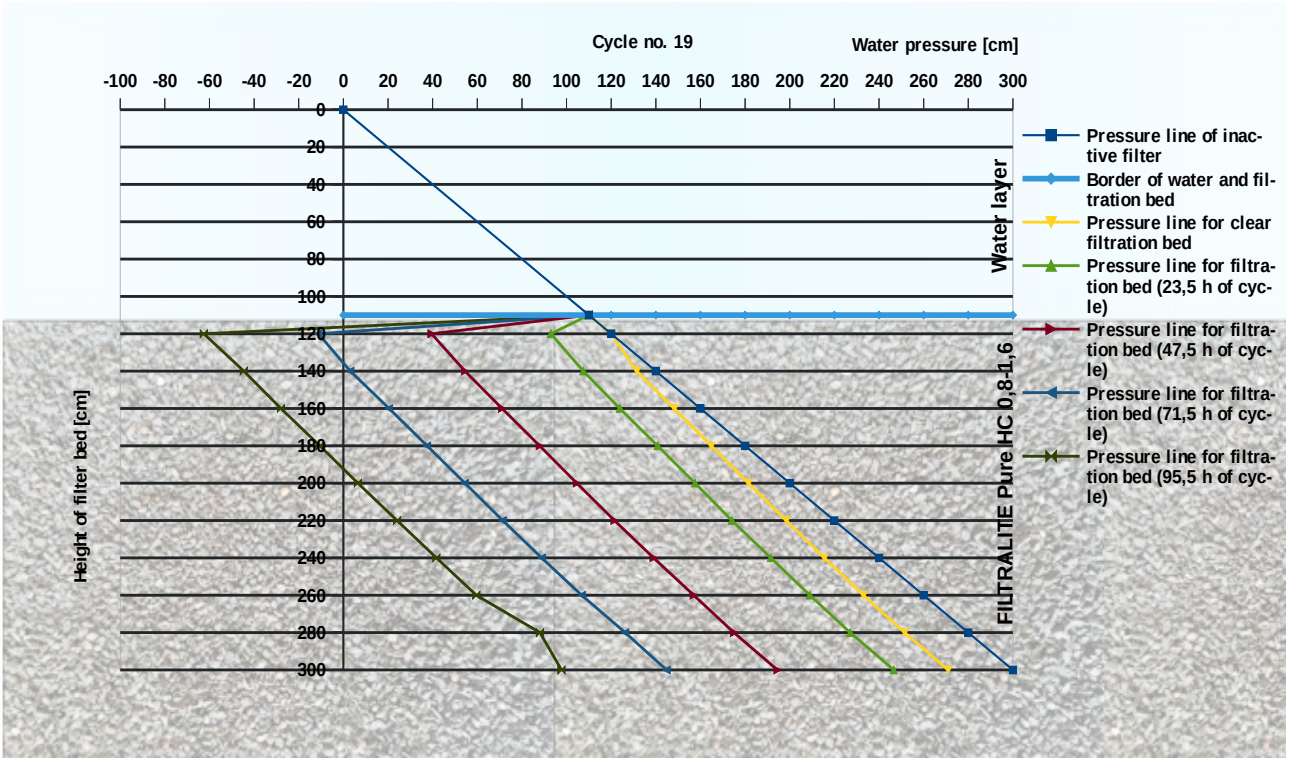


Fig. 127 Head loss at consecutive media depths in the filtration cycle no. 20 for filtration rate 9 m/h

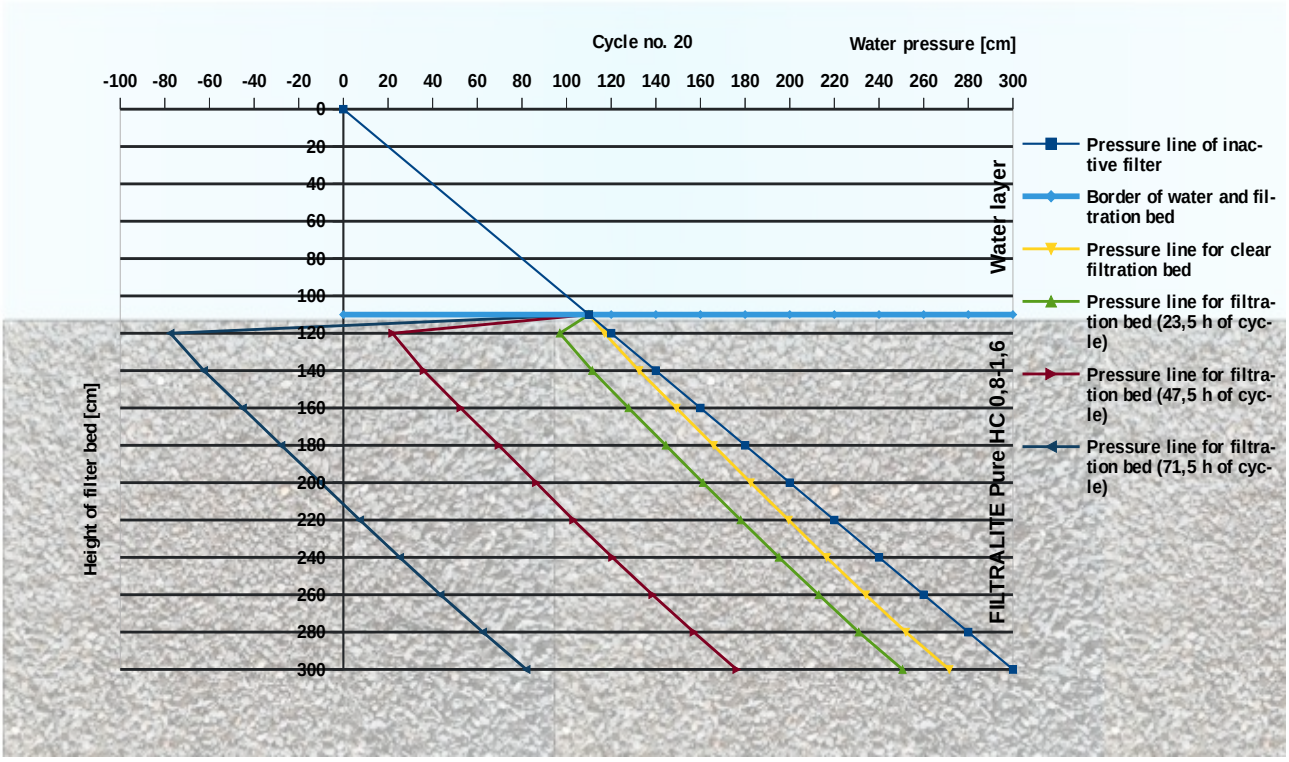


Fig. 128 Head loss at consecutive media depths in the filtration cycle no. 1 for filtration rate 12 m/h

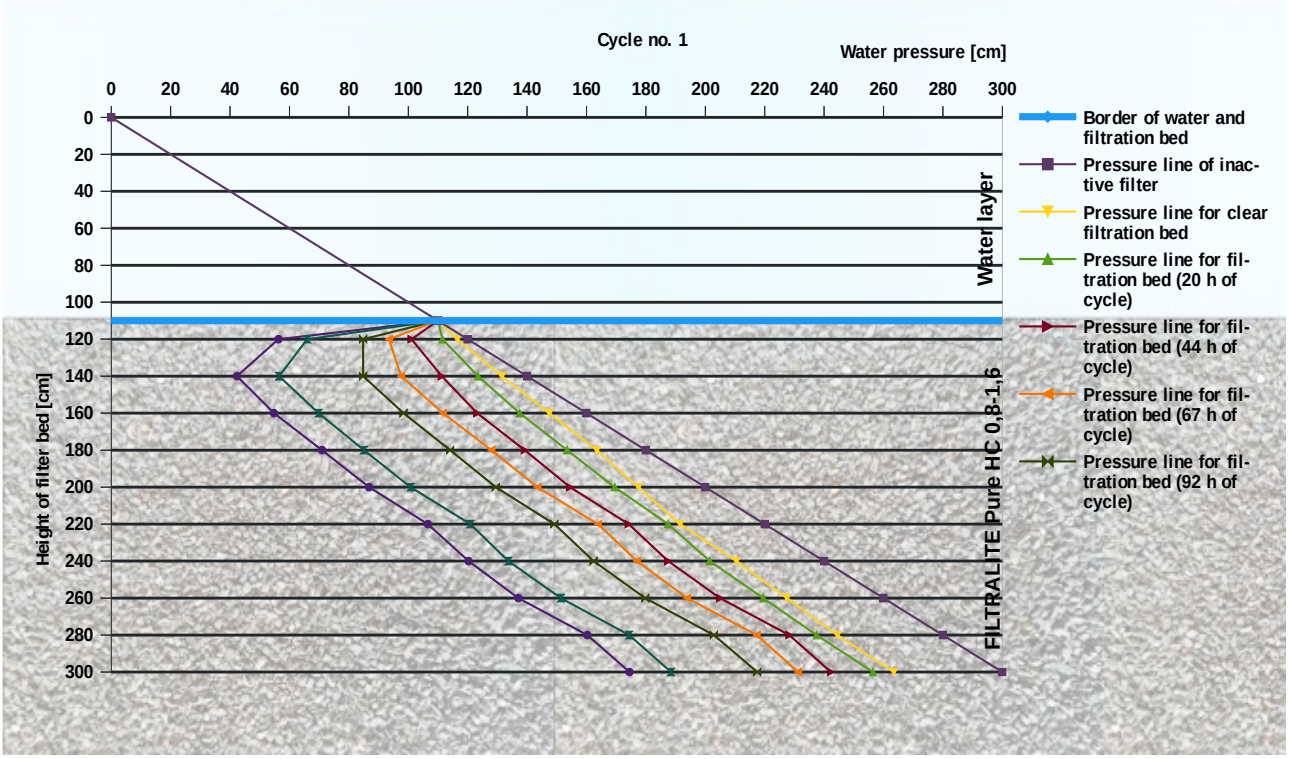


Fig. 129 Head loss at consecutive media depths in the filtration cycle no. 8 for filtration rate 12 m/h

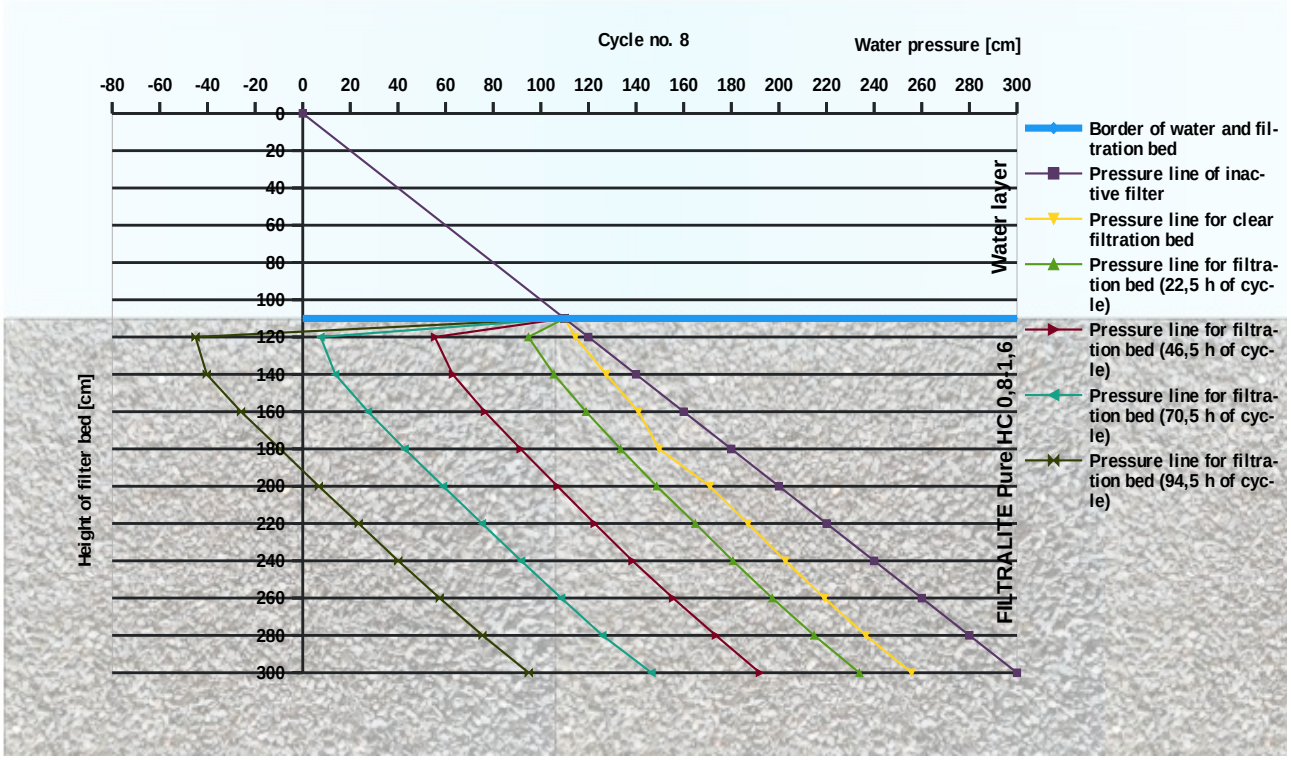


Fig. 130 Head loss at consecutive media depths in the filtration cycle no. 16 for filtration rate 12 m/h

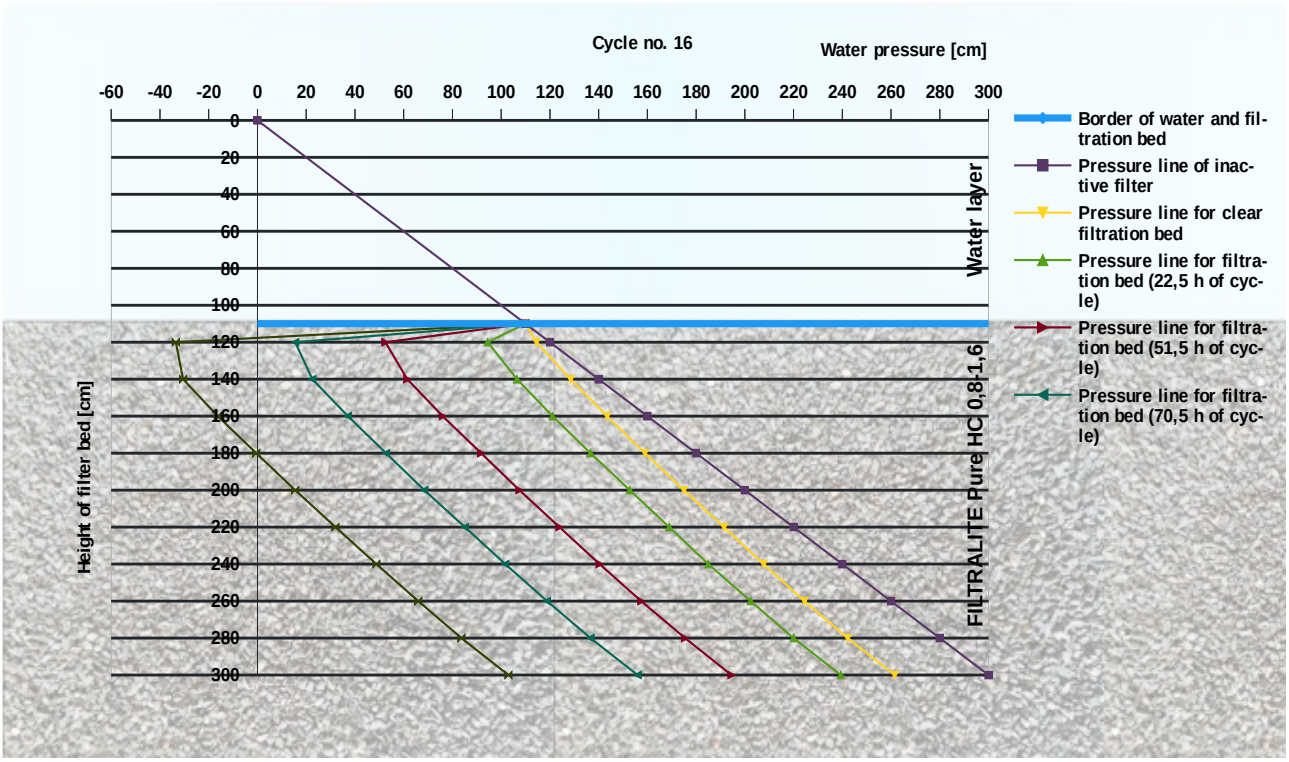


Fig. 131 Head loss at consecutive media depths in the filtration cycle no. 19 for filtration rate 12 m/h

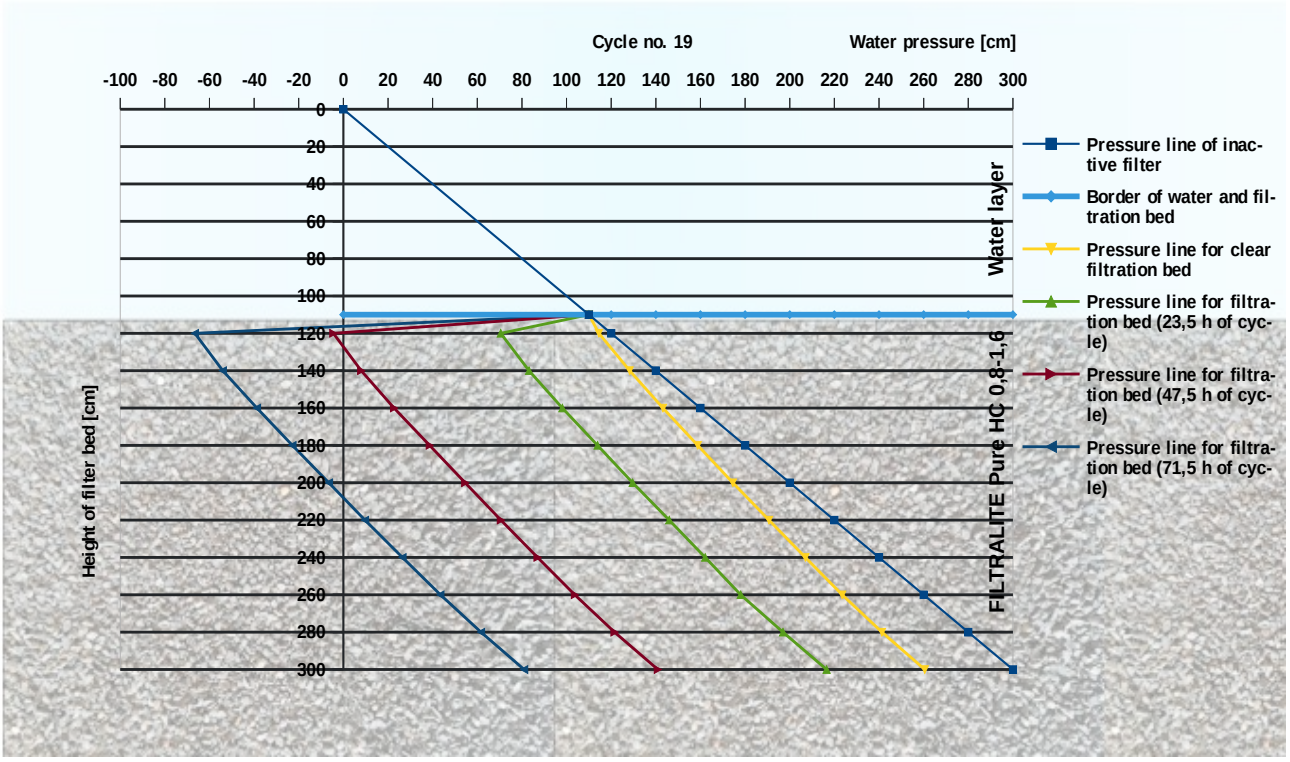
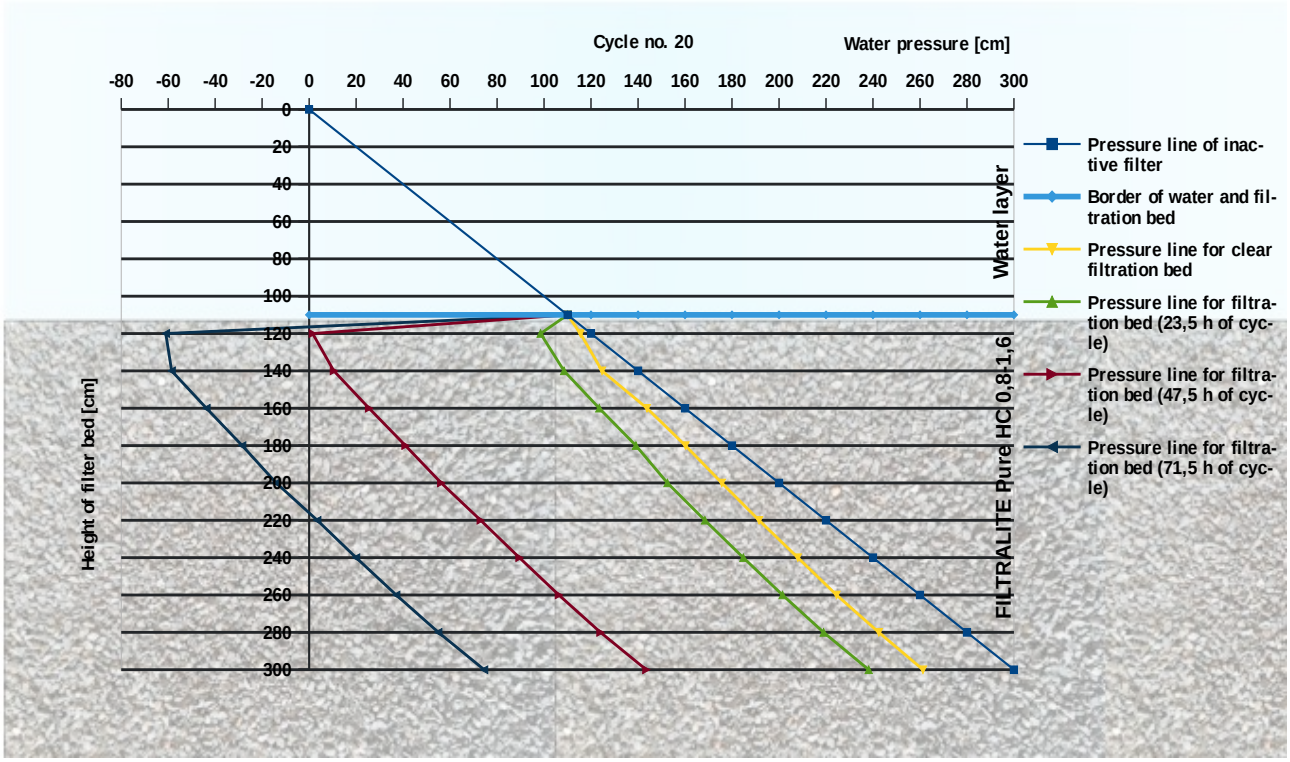


Fig. 132 Head loss at consecutive media depths in the filtration cycle no. 20 for filtration rate 12 m/h



The conclusions from this analysis are following:

- the longer the filtration cycle, the bigger the final head loss,
- in the studied setup (gravitational filtration with constant water pressure), underpressure occurred at some time in the cycle. Due to different filtration rates the results were unique for every rate.
- The underpressure is undesired phenomenon. The moment at which underpressure is observed is strongly linked to the material type. The light weight and porosity of Filtralite makes the underpressure to occur later, than for non-porous material. This feature allow to have longer filtration cycles without underpressure.
- The negative effect of underpressure can be:
  - Filling of media voids with gases, that limits the filtration surface,
  - Release of gas bubbles, that cause a slight air backwash effect. Contaminants may pass the filter.
- The vaporization of gas is observed during filtration rate alternation (especially while lowering the rate). Thanks to that, it has not been observed in the research setup, but at the backwash pauses.

The avoid underpressure in the full scale open filters, a freeboard must be high enough. A straightforward calculation of tested freeboard height + recorded underpressure will yield the total freeboard securing form underpressure occurrence.
The highest underpressure measured for Filtralite media was 80-100 cmH_2O. The existing freeboard in the test columns was 110 cm. That means, that for Filtralite 200 cm freeboard will be absolutely sufficient in the limits of tested conditions.

The general recommendation for designing open filters is to maximize the freeboard. This rule is very important for raw water with high suspension content (organic and inorganic), where significant head loss buildup is expected. Some of the existing filters have the freeboard shorter than 100 cm, and in seldom cases the freeboard is as extremely short as 50 cm. The common operational problem is shortening the filtration cycle. To overcome it, dual media bed can be used. The top layer (lighter, coarse) will reduce the effect of quick head loss buildup and consequently will help to avoid underpressure.

4.16. Backwashing Filtralite Pure HC 0,8-1,6

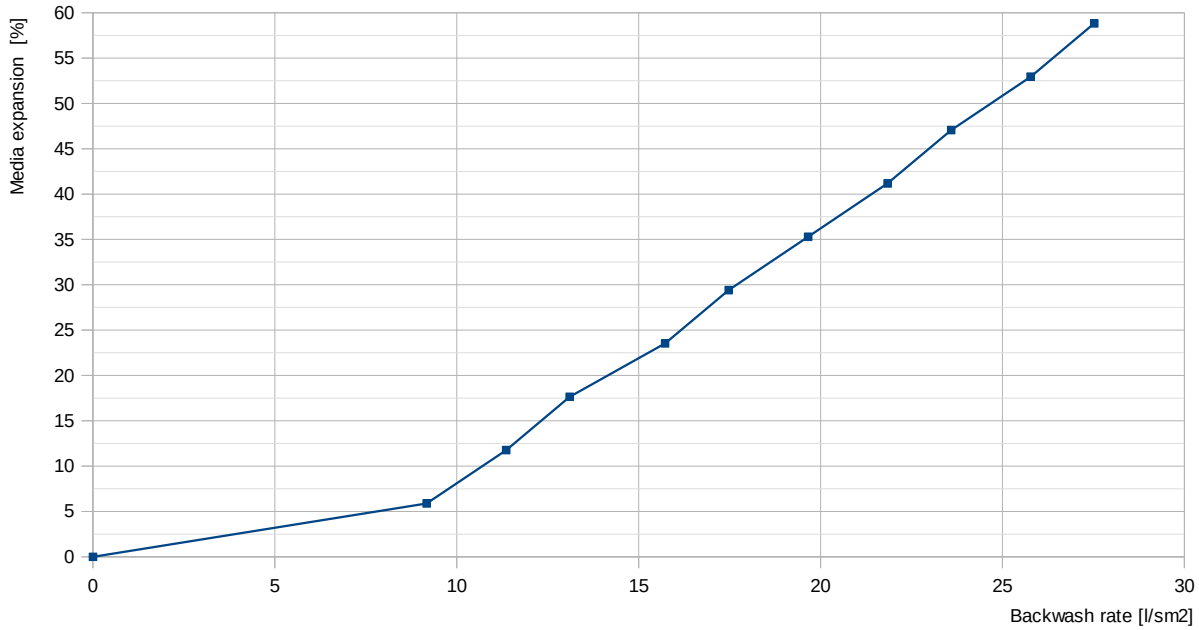
The backwash procedure was engaged every 7 days. During backwashing the relation between backwash rate and media expansion have been established. The results are presented in the table below.

Tab. 4 Backwash rate and respective media expansion

Media expansion [%]	**Backwash rate [l/sm^2]**
6	9,17
12	11,36
18	13,11
24	15,73
29	17,47
35	19,66
41	21,84
47	23,59
53	25,77
59	27,52

The relation is presented on the graph below.

Fig. 133 Media expansion in terms of backwash rate

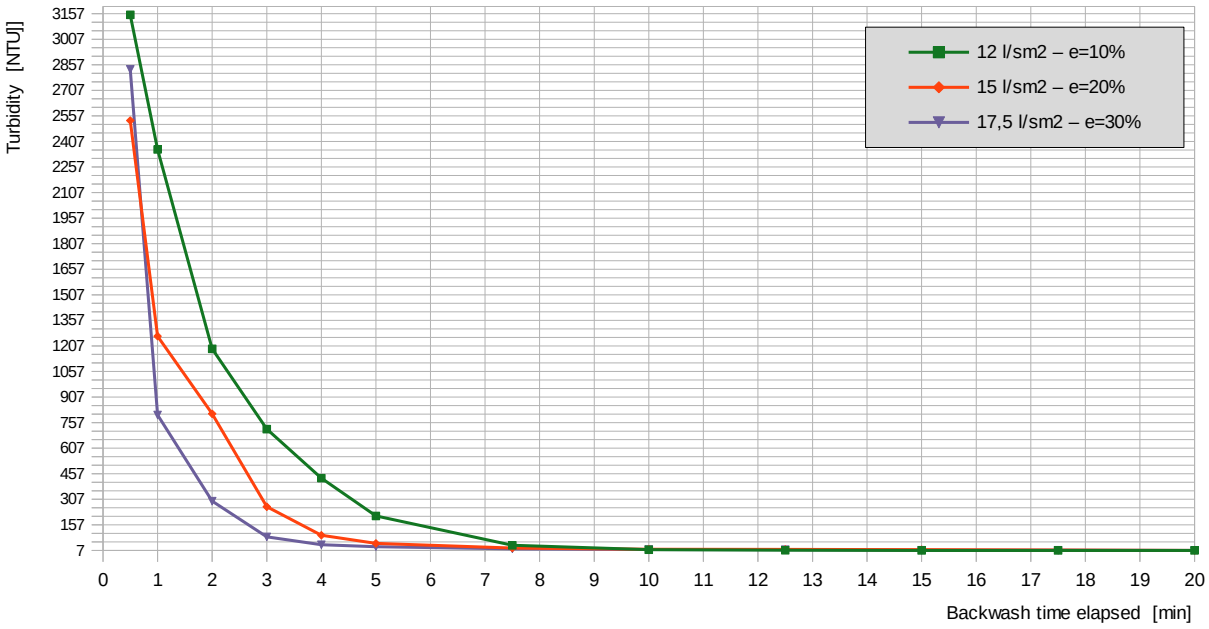


To develop the best backwash procedure the quality of backwash water was monitored during complete backwash routine at 10, 20 and 30% expansion. The results are shown in the tab.5 and fig. 134.

Tab. 5 Turbidity of backwash water at 12,0, 15,0 and 17,5 L/sm^2 backwash rates

Backwash time elapsed [min]	Turbidity of backwash water [NTU]	Backwash time elapsed [min]	Turbidity of backwash water [NTU]	Backwash time elapsed [min]	Turbidity of backwash water [NTU]
C1 – backwash rate 12 L/sm^2		C2 – backwash rate 15 L/sm^2		C3 – backwash rate 17,5 L/sm^2	
0,5	3150	0,5	2530	0,5	2830
1	2360	1	1264	1	802
2	1190	2	809	2	296
3	719	3	263	3	86
4	431	4	96	4	40
5	209	5	48	5	29
7,5	37	7,5	21	7,5	16
10	11	10	14	10	12
12,5	8	12,5	13	12,5	11
15	7	15	11	15	8
17,5	7	17,5	9	17,5	8
20	7	20	7	20	7

Fig. 134 Change in the turbidity of backwash water at 12, 15, 17,5 m/h backwash rates



4.17. Photographs of worked-in Filtralite Pure HC 0,8-1,6 media at consecutive depths

In this chapter photographs of the media are presented. The photos were taken for every column (working at 6, 9 and 12 m/h) at various depths after the study has ended (May 2019). The sampling nozzles arrangement corresponded to 0,10 m; 0,30 m; 0,50 m; 0,70m, 0,90 m; 1,10 m; 1,30 m; 1,50 m and 1,70 m of media depth.

- Photographs of Filtralite media (filtration rate 6 m/h)

Pic. 7 C1 – media at 0,00 – 0,10 m depth

Pic. 8 C1 – media at 0,10 – 0,30 m depth

Pic. 9 C1 – media at 0,30 – 0,50 m depth

Pic. 10 C1 – media at 0,50 – 0,70 m depth

Pic. 11 C1 – media at 0,70 – 0,90 m depth

Pic. 12 C1 – media at 0,90 – 1,10 m depth

Pic. 13 C1 – media at 1,10 – 1,30 m depth

Pic. 14 C1 – media at 1,30 – 1,50 m depth

Pic. 15 C1 – media at 1,50 – 1,70 m depth

Pic 16 C1 – support layer

- Zdjęcia warstw złoża dla kolumny pracującej z prędkością 9 m/h

Pic. 17 C2 – media at 0,00 – 0,10 m depth

Pic. 18 C2 – media at 0,10 – 0,30 m depth

Pic. 19 C2 – media at 0,30 – 0,50 m depth

Pic. 20 C2 – media at 0,50 – 0,70 m deth

Pic. 21 C2 – media at 0,70 – 0,90 m depth

Pic. 22 C2 – media at 0,90 – 1,10 m depth

Pic. 23 C2 – media at 1,10 – 1,30 m depth

Pic. 24 C2 – media at 1,30– 1,50 m depth

Pic. 25 C2 – z media at 1,50 – 1,70 m depth

Pic. 26 C2 – support layer

- Zdjęcia warstw złoża dla kolumny pracującej z prędkością 12 m/h

Pic.. 27 C3 – media at 0,00 – 0,10 m depth

Pic. 28 C3 – media at 0,10 – 0,30 m depth

Pic. 29 C3 – media at 0,30 – 0,50 m depth

Pic. 30 C3 – media at 0,50 – 0,70 m depth

Pic. 31 C3 – media at 0,70 – 0,90 m depth

Pic. 32 C3 – media at 0,90 – 1,10 m depth

Pic. 33 C3 – media at 1,10 – 1,30 m depth

Pic. 34 C3 – media at 1,30 – 1,50 m depth

Pic. 35 C3 – media at 1,50 – 1,70 m depth

Pic. 36 C23 – support layer

5. CONCLUSIONS AND DESIGNING GUIDE

The most important observation and conclusion from the study are:

- Filtralite Pure HC 0,8-1,6 media does remove mineral iron from ground water instantaneously after filtration starts, regardless of filtration rate.
- Very high effectiveness of iron removal has been achieved confirmed by outlet analysis (only traces of iron below detection limits were present).
- Even at 12 m/h filtration rate a stable iron concentration (below 0,05 mg/L) in treated water has been recorded.
- Initial manganese removal remained at 30% reduction before complete work-in. This effect is considered to be an adsorption on Fe2O3 precipitate.
- The complete work-in for manganese removal was observed for 6 m/h filtration rate at first. It has been 85 days of constant filtration until the manganese content in treated water reached lower concentration than the regulation limit. The fluctuations of manganese content in treated water is linked to imperfection in sampling technique. Such results were recorded previously with the research setup and different filtration media. However, in full scale the manganese removal performed way better (after the work-in) and manganese content in treated water was significantly below the regulation limit.
- The complete work-in for Mn removal has been achieved after 100 days of constant filtration for filtration rate 9 m/h.
- In the whole research period the work-in for manganese removal was not completed for 12 m/h filtration rate. However, there was a clear trend of manganese removal improvement in the final month of filtration. Due to high filtration a complete work-in would be expected in some time.
- The most superior performance has been observed for ammonium ion removal. The work-in for biological denitrification was shorter than 30 days for all tested filtration rates. The complete work-in was assumed, when NH^{4+} concentration was close to 0 mg/L in treated water. This property makes Filtralite an outstanding material for the ammonium ion removal processes.
- A stable removal of NH^{4+} has been observed until the end of the research. The fluctuations in the effectiveness were linked to refurbishments in the DWTP. The raw water needed to be disinfected, what affected the research setup.

The research study of Filtralite Pure HC 0,8-1,6 proved, that the media is highly useful in Fe and NH^{4+} removal. (especially the performance for NH^{4+} removal is super effective)
On the other hand manganese removal is effective after the work-in. For a full scale application it is necessary to include the work-in time and requirement in implementation procedure. Otherwise, a catalytic media must be added to the filter (as the most bottom layer).

The conducted study involved only natural work-in for manganese removal. No alternative techniques have been tested (potassium permanganate or hypochlorite oxidation), since very few DWTP choose this method for the full scale implementation.

The observation and data collected during the study are presented in the form of conclusions, designing guide and operation recommendations in the next section.

5.1. Iron removal with Filtralite Pure HC 0,8-1,6

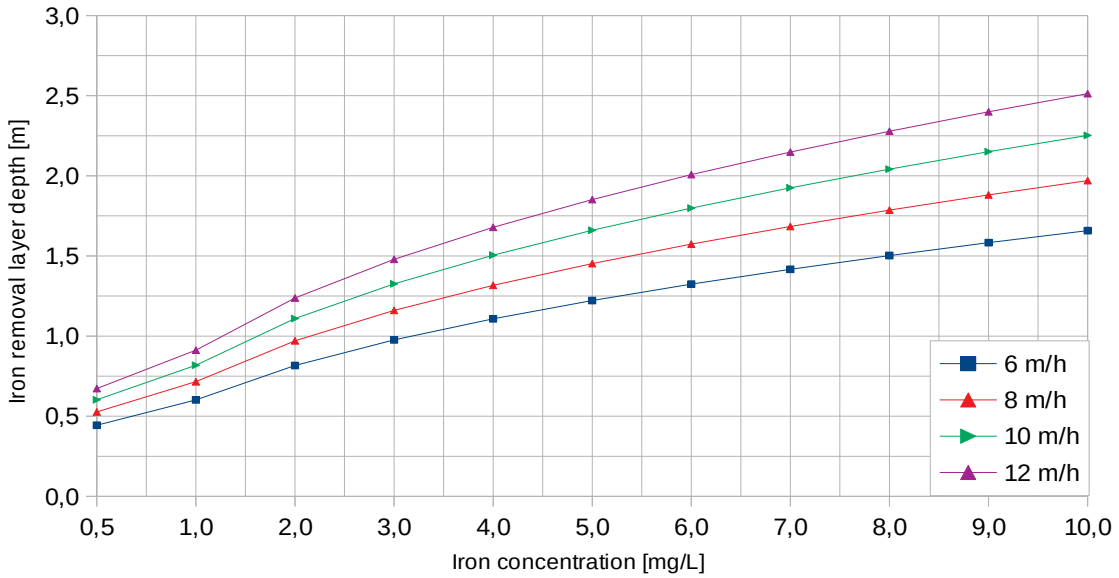
Work-in time:
For ground water inorganic iron the removal process should work after the filtration start, under following conditions:

- Sufficient media depth (described in details below),
- Sufficient and constant oxygen supply through raw water aeration. 0,5 mgO_2/L per every 1,0 mgFe/L,
- Proper pH (optimal 7,0-7,5).

For every extraordinary alternation of the above conditions an individual consultation should be done.
Required media depth:
The required depth of iron removal layer is dependent on filtration rate and Fe concentration in raw water.

The approximate relation between media depth and Fe raw water content for various filtration rates is given in the Fig.135.

Fig. 135 The approx. relation of iron removal layer depth vs. Fe content in raw water



Usually filtration rate is either fixed for existing plants or assumed preliminary for new designs.
Knowing filtration rate and Fe content in raw water it is possible to estimate required media depth for iron removal process.

NOTE! The trend is given for 50% iron oxidation in aeration process prior to filtration.
For lower extent of pre-oxidation the required media depth shall be proportionally bigger.
The absolutely necessary condition for iron removal is a sufficient oxygen supply.
The presented trend will conform in majority of real cases. Occasionally the real media depth may be different than estimated.

There is no upper limit for Fe concentration in raw water, that the media would not be able to remove. However, for high Fe loads the following must be considered:

- the higher the concentration of Fe, the shorter the filtration cycle,
- oxygen supply might be a limiting factor
- the higher the concentration of Fe, the higher the iron removal layer. The total media depth will be bigger.

In general it is recommended to do a technological consultation and/or pilot test for Fe concentration exceeding 5,0 mg/L.

5.2. Ammonium ion removal with Filtralite Pure HC 0,8-1,6

Work-in time:
The ammonium ion removal should start after 4-8 weeks of constant filtration. The time is needed for the denitrification biofilm development.

The work-in process can be disturbed by:

- insufficiency of dissolved oxygen in filtration water. Recommended amount is 4,5 mgO_2/L per every 1,0 mgNH^{4+}/L,
- pH much different than optimal (7,0-7,5),
- application of disinfectants (both to raw water and backwash water),
- lack of phosphates in raw water.

It is recommended to do a technological consultation if denitrification process is not running properly.

The work-in is achieved in a constant steady filtration. Any longer pauses in filtration will retard the work-in process. Biofilm development and performance is especially vulnerable to filtration breaks, since no nutrients are supplied to the biomass then.

Required media depth:

- NH^{4+} removal only – 0,8 m of media depth per every 1,0 mgNH^{4+}/L. Filtration rate higher than 12 m/h is not recommended.
- Simultaneous Fe and NH^{4+} removal – the required media depth should be calculated for both contaminants, and whichever is the bigger shall be chosen for the process.
- Simultaneous Fe, Mn, NH^{4+} removal – the media depth should be estimated as for single stage manganese removal (given in the next section). The exception form this rule applies if NH^{4+} removal layer estimation would yield higher depth (this case is very seldom).

NOTE! The absolutely necessary condition for ammonium ion removal is a sufficient oxygen supply. The practical extent of NH^{4+} removal is limited to 2,0-2,5 mg/L. This limitation results from possible oxygen supply in a single stage filtration (and is independent of media type).
For higher content of NH^{4+} (than 2,5 mg/L) it might be necessary to divide filtration into two stages with additional intermediate aeration.

5.3. Manganese removal with Filtralite Pure HC 0,8-1,6

Work-in time:
The formation of MnO_2 layer on the media grains is vital for the chemical (catalytic) manganese removal process.
However, this work-in is a bioprocess, which length depends on:

- Mn content in raw water. The higher Mn content (more substrate for oxidation) the faster the process
- Fe content and how effective it is removed in the upper layers of the filter
- Amount of dissolved oxygen (remaining after Fe and NH^{4+} removal). Recommended amount is 0,75 mgO_2/L per every 1,0 mgMn/L.

The work-in time is expected to take place in less than 100 days of constant filtration, if Mn concentration in raw water >0,25 mg/L and filtration rate is <10,0 m/h

NOTE! Work-in time increase significantly for filtration rates >10,0 m/h.

Required media depth:

- Simultaneous Fe and Mn removal – the media depth estimation for Fe removal should be augmented by additional 0,5 m.
- Mn removal only (ex. 2^{nd} stage filtration) – minimum of 0,5 m media depth should be used. The recommended depth is 1,0 m, which is sufficient to shield the most bottom manganese removal layer from any trace iron remaining at inlet of 2^{nd} stage filtration.

NOTE!
Filtralite media can be used with other heavier media (catalytic).
This method has important advantages:

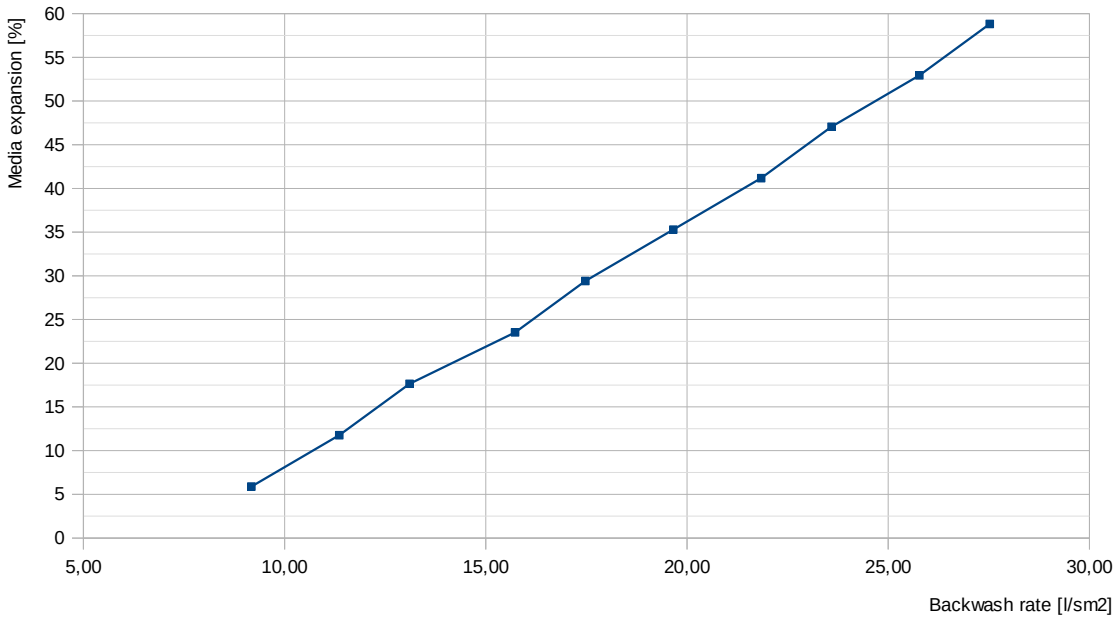
- Instantaneous effect of Mn removal (without work-in period)
- Catalytic media are much heavier than Filtralite, which guaranties no intermixing and correct order of layers in the filter.
- Recommended backwash rates are similar for catalytic media and Filtralite, which favors successful backwashing of dual media filters
- Some of the bottom layers of Filtralite (just above the catalytic media) will undergo natural work-in, which will enhance the Mn removal even more.

In the full scale investments investors often choose catalytic media over natural work-in media (despite of higher CAPEX), to avoid work-in time and effort.

5.4. Backwashing Filtralite Pure HC 0,8-1,6

It is possible to backwash Filtralite Pure media with air and water. The backwash procedure typically use in ground water treatment is suitable for Filtralite as well.
Filtralite media has an advantageous expansion profile for desirable backwash rates, which makes the backwash process fast and effective. This property helps to limit the overall backwash water consumption.

Media expansion in terms of backwash rate is shown in Fig. X (water temp. approx. 10 °C).



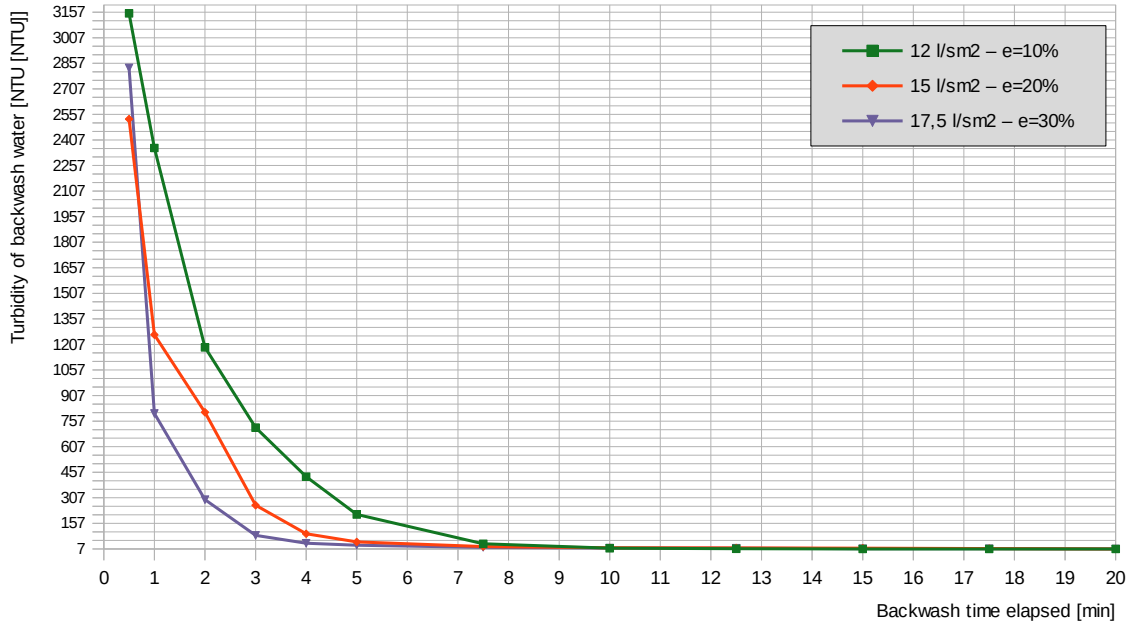
The standardized backwash procedure:

1. Lowering the water level in the filter, to the level just above the media.
2. Air backwashing up to 5,0 min. with intensity 12,5-17,5 L/sm^2 (45,0-63,0 m/h).
3. Water backwashing. The intensity must be matched with available freeboard to avoid media wash away. Backwash time must be adjusted individually upon attaining clear backwash water. The recommended backwash intensity is 12,5-17,5 L/sm^2 (45,0-63,0 m/h).

NOTE!

It is recommended not to apply water backwash rate less than 7,5 L/sm^2. For this low and lower backwash rate attaining clear backwash water may take unreasonably long.

On the other hand the higher the backwash rate, the shorter the backwash required for clear backwash water. The dependence is depicted in the graph below.



To sum up, the optimal backwash process utilize the highest possible backwash rate, which is not high enough to wash away the media from the filter.

In every tested backwash scenario, the successful backwash time has been less than 10 minute. This is an evident indication for the ease and effectiveness of Filtralite media backwashing.

5.5. Filtration cycle duration

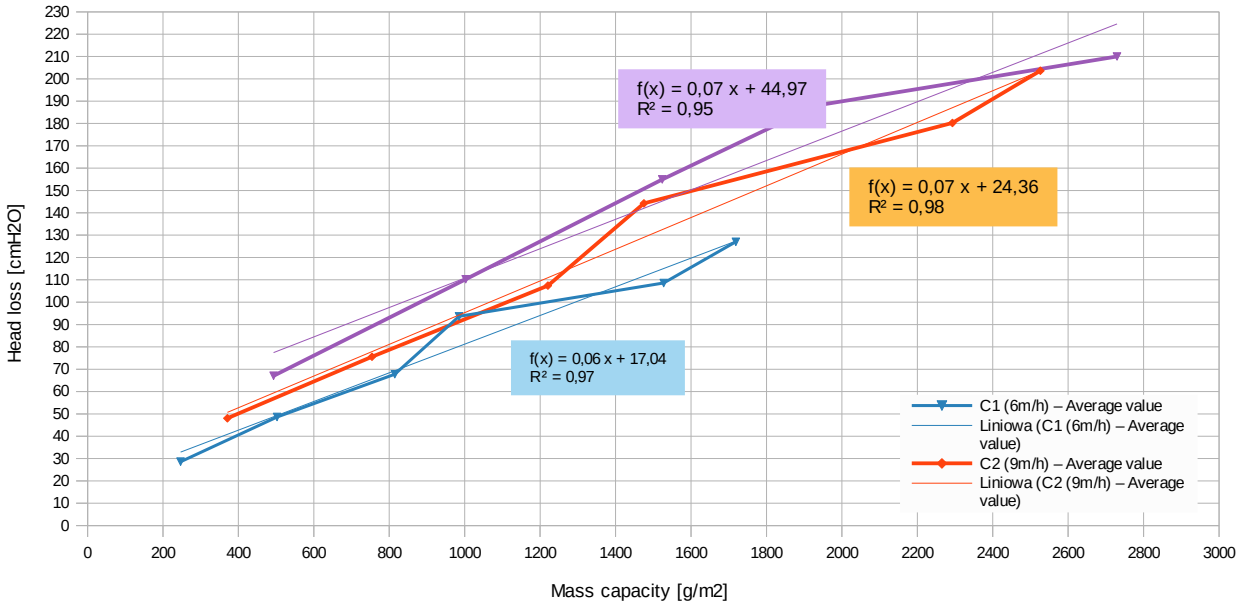
The recommended filtration cycle shall be calculated with respect to the load of contaminants and should not exceed the equivalence of:

- 2500,0 g/m^2 for simultaneous Fe and Mn removal
- 3000,0 g/m^2 for Fe or other suspended contaminants removal only.

Aside from designing routines, this assumption should be verified in the full scale implementation and adjusted if needed.
The optimal filtration cycle duration is also balanced by treated water quality. There is a need of control especially in the last period of the filtration cycle.

As more contaminants are stored in the filter the head loss buildups. The average relation between head loss and mass capacity (with respect to Fe_2O_3) for every filtration rate tested is given in the graph below. 50% of iron has been oxidized prior to filtration.

This relation is a guideline for the head loss estimation in designing water treatment processes with Filtralite Pure HC 0,8-1,6.



In general the total head loss should not exceed:

- 3,0 mH_2O in gravitational filtration (including the pressure exerted by the freeboard),
- 5,0 mH_2O in pressure filtration.

Every case should by analyzed individually in terms of total (maximal) head loss.

6. IMPLEMENTATION AND OPERATION RECOMMENDATIONS

1. Installation of the filtration media

- Check the condition of the outlet drain and the backwash nozzles (test the air backwash system when empty filter is filled 10cm with clear water).
- Install the supporting layer of appropriate grain size, that is adequate to the drain holes size.
  NOTE! It is admissible to install Filtralite media directly on the outlet drain, if the drain type will hinder the media grains from passing the drain holes.
- Install the media. In case of multi-layer media keep the order of heavier and finer material in the bottom, and lighter and coarser on the top.
- Run the initial backwash until the backwash water is clear.
- Disinfect the media with hypochlorite.
- Ensure the filter is ready to work, confirm with lab analysis the media condition after disinfection.

2. Maintenance of the media in operation

The regular condition control of the media is recommended.

- Media depth control (at least once a year). Compare the current depth with original level or last measurement. Either increase or decrease in media depth is an indication of faulty backwash procedure, that needs adjustment.
- Backwash water control (systematically for every backwash). Check for grains of the media in the backwash water, to ensure the media is not washed away during the backwash.