Efficiency of Membrane Ultrafiltration in Water Treatment Plant Jasná

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Abstract. Ultrafiltration (UF) is a membrane separation process by which the particles of mechanical nature are removed from the water. Thanks to the pore diameter that are the order of tenths nm and the material, constructional and chemical properties of UF membranes, this technology represents the final solution for a secured protection against the turbidity that is caused by content of non-soluble and colloid particles of organic and inorganic origin, bacteria and the majority of viruses. Ultrafiltration was investigated within the pilot-plant tests at the WTP Jasná during the treatment of surface water originating from the water source Zadná voda. Water treatment is in this locality focused on turbidity that is caused by storm rainfalls and snow thawing. Fully automated ultrafiltration equipment with the membrane modul UA-640 (Microdyn-Nadir) was used. On the base of filtration cycles, the effectiveness of membraned technology was evaluated. Water was supplied to the UF-device by the pump, so the UF-flow rate was invariably maintained at the 600 L/h. Period of filtration cycle was 30 minutes. Following the end of the cycle, washing of membrane by using the back-flushing by water and air was applied. Filtered water accumulated in the tank was used for back-flushing while the air was supplied by the air-pump connected to the device. Any way of washing of the membrane did last for 30 seconds. On the base of filtration cycles, the effectiveness of membraned technology was evaluated. Turbidity removal is the major issue at the WTP Jasná. Limit for turbidity 5 NTU is set by Decree No. 247/2007 Col. Measuring data provided that the turbidity level of water treated by using the ultrafiltration device are compliant with the legal limit for drinking water. By using the ultrafiltration, the decrease by 76,1% has been reached in the first experiment (average turbidity in raw water 1,55 NTU). The efficiency of turbidity removal was 95,2% that was reached by ultrafiltration of water with a higher level of turbidity (average turbidity in raw water 8 NTU). High effectiveness of ultrafiltration was reached also with the water with the turbidity 37 NTU. In all of the three experiments, the turbidity of treated water ranged between 0,37 – 0,38 NTU.

1. Introduction
Water treatment plant Jasná is located in the region of Liptov, in central Slovakia, more-accurately on the top part of Chopok which is located above the village Demänovská Dolina. This particular locality is one of the most famous tourist and ski centre in Slovakia. Hand in hand with the development of tourism, it is important to ensure the sufficiency of water suitable for drinking.

WTP was constructed in 1999. It serves the purpose of drinking-water treatment of the water originating from the water-source Zadná voda, which the water is supplied from after the mechanical
pre-treatment to the WTP, to water reservoir and to consumers by using the gravitational transfer of water. Design capacity of the WTP is 15 L/s. Water treatment is in this locality focused on turbidity that is caused by storm rainfalls and snow thawing.

**Ultrafiltration (UF)** is a membrane separation process by which the particles of mechanical nature are removed from the water. Thanks to the pore diameter that are the order of tenths nm and the material, constructional and chemical properties of UF membranes, this technology represents the final solution for a secured protection against the turbidity that is caused by content of non-soluble and colloid particles of organic and inorganic origin, bacteria and the majority of viruses [1,2].

Treatment of water from surface water sources that are polluted mechanically or biologically, pre-treatment before the next technological step of water treatment are among the typical applications where the UF is used in. Effectiveness of ultrafiltration is increased by conventional methods such as coagulation, sedimentation and flotation [3].

The primary advantages of UF membrane processes are compared with conventional clarification and disinfection (post-chlorination) processes are:

• No need for chemicals (coagulants, flocculants, disinfectants, pH adjustment)
• Size-exclusion filtration as opposed to media depth filtration
• Constant quality of the treated water in terms of particle and microbial removal
• Process and plant compactness
• Simple automation

Ultrafiltration represents a separation process that is powered by the pressure while the pressure impuls is caused by formation of vacuum or by the act of higher pressure from the outer side. The flow throughout the membrane ranges between 40-200 L/m².h. Asymmetric membranes are used in ultrafiltration and the separation process is also functional on the principle of sieve mechanism. Pore size of UF-membrane ranges from 0.01 to 0.1 µm and the difference in pressure is from 1-10 bar. Most frequently mentioned is the value for molecular weight cut off, MWCO, that ranges between 5 – 5000 kDa and indicates the lowest molecular weight of testing polymer that is 90% retained on the membrane. For a proper design it is essential to select a membrane with a lower MWCO than is the molecular weight of substances to be effectively removed. Shape of the molecule has a great impact on separation, as the linear molecules do pass the membrane through but the spheroidal molecules of the same size can be caught on it [4-6].

UF-modules are available in various constructional versions, e.g. of boards, framed, spiral winding and tubular. Each version is suitable to be used in different processes. Spiral winding modules are used for clean water, framed modules for high concentrated solutions and tubular modules are used in the treatment of drinking water [3,7].

Membranes of an ultrafilter consist of a bunch of hollow fibres where the functional surface represents an approximately 0.2 µm rough surface film of fiber hollows. Total filtration surface of one membrane standardly ranges between 40–60 m² in industrial modules. Fibers can be made of one or more hollows. Design and size of hollows is selected based on the level of pollution of the raw water. Hollows of larger diameter are preferred when the content of non-soluble substances is higher (>50 mg/L), however the result of it is a smaller filtration surface of the membrane module [8,9].
For manufacturing of the UF-membranes, materials of many kinds can be used, but when taking into account the mechanical and chemical durability, predisposition to siltation and the price the materials that were approved the most are polysulphone (PSO), polyethersulphone (PES), polyacrylnitrile (PAN), polytetrafluoroethylene (PTFE), polyvinylidene fluoride (PVDF), cellulose acetate (CA), polyamid (PA) and polypropylene (PP). Manufactured are also the more expensive ceramic UF-membranes (Al₂O₃, TiO₂, ZrO₂, SiO₂, SiC). However, these are rather used in microfiltration, or eventually in applications related with a need for thermic disinfection (food and pharmaceutical industry). Under the constant load on the membrane they are resistant to water with pH 3-10 and for a short term they resist the chemical washing of membrane at the pH ranging between 1-13. Membranes are resistant to the standardly used disinfectants (max. 20 mg/L NaClO) [8,9].

Filtration cycle consists of filtration, forward-flush and upstream washing. Length of one cycle depends on the level of pollution of raw water. Usually, the phase of filtration takes 40-180 minutes and is followed by forward-flushing phase taking 30-50 seconds and upstream washing that takes 40-90 sec. Consumption of washing water ranges regularly between 2-4% from produced water, depending on the non-soluble substances content at the entry point [9].

Chocking of membranes can happen via the series of physico-chemical and biological mechanisms. Those mechanisms contribute to a higher accumulation of solid particles on the surface and within the membranes structure which results in that transmembrane pressure gets increased and the filtration velocity gets decreased. This leads to that the filtration cycle is shortened and the more frequent washing of membrane is needed [5].

We recognize external and internal clogging. External clogging on the membrane surface (scaling) causes the composition of the filtered medium from which the minerals on the membrane surface crystallize to form a filter cake and block the passage through the membrane. This kind of membrane fouling is temporary. External clogging can also cause so-called biofouling by forming biofilms or polymer layers on the membrane surface. The membranes so clogged are cleaned with oxidizing agents, weak sodium hypochlorite solutions are most commonly used. The fouling occurs in the pores of the membranes, representing the physical fouling of the pores by the pores where the pores are blocked and adsorbed, leading to a narrowing of the pores. This clogging is permanent.

2. Material and Methods

2.1. Quality of water source in WTP Jasná

In the Table 1 is presented the analysis of water that was sampled at low values for turbidity at the water source Zadná voda on 18 April 2018. In terms of physico-chemical requirements, water is complying with the provisions of Decree no. 247/2017 Col. which laid down the requirements on water intended for human consumption and on the control of quality of water intended on human consumption. Water from the source Zadná voda is characterized by a very low mineralisation and an intermittent high value for turbidity, what is caused by the type of source of the drinking water.
Table 1. Water quality at the entry point to the mechanical filtration premises

| Parameter          | Unit | Raw water | Parameter          | Unit | Raw water |
|--------------------|------|-----------|--------------------|------|-----------|
| pH                 |      | 7.91      | chlorides          | mg/L | 3.28      |
| Conductivity       | mS/m | 2.27      | nitrates           | mg/L | 0.86      |
| COD\textsubscript{Mn} | mg/L | 0.56      | nitrites           | mg/L | 0.005     |
| Turbidity          | NTU  | 1.05      | sulphates          | mg/L | 1.92      |
| Colour             | mg/L | 5         | fluorides          | mg/L | 0.08      |
| Alkalinity         | mmol/L | 0.268 | ammonia            | mg/L | 0.013     |
| Total dissolved solids | mg/L | 20       | potassium          | mg/L | 0.25      |
| Ca+Mg              | mmol/L | 0.159 | sodium             | mg/L | 0.94      |
| Fe                 | mg/L | 0.02      | calcium            | mg/L | 3.29      |
| Mn                 | mg/L | 0.001     | magnesium          | mg/L | 1.87      |

2.2. Ultrafiltration module

Fully automated ultrafiltration device, equipped with the membrane module UA-640 (Microdyn-Nadir) and control system and measuring the transmembrane pressure and back-flushing of the membrane with water or air, with chemical washing option, was used within the experiments (Figure 2). Specifications of modul UA-640 are listed in Table 1.

Table 2. Modul UA-640 specifications

| Membrane type                   | Modul with hollow fibres | Peak-flow | do 1.3 m\textsuperscript{3}/h |
|---------------------------------|--------------------------|-----------|-----------------------------|
| Diameter of fibers              | OD/ID: 2.1 mm/1.1 mm      | Max. trans-membrane press. | 1 bar                       |
| Membrane material               | PAN - polyacrylnitril    | Max. pressure of module    | 2 bar                       |
| Diameter of poruses             | 0.025 µm                 | Module diameter           | 168 mm                      |
| Membrane surface                | 16 m\textsuperscript{2}  | Modul lenght             | 1210 mm                     |
| Regeneration                    | Backwashing - water and air | Maximum turbidity      | 300 NTU                     |

Figure 2. A view of the ultrafiltration device, the membrane module itself, the control system and the treated water storage tank

Water was supplied to the UF-device by the pump, so the UF-flow rate was invariably maintained at the 600 L/h. Period of filtration cycle was 30 minutes. Following the end of the cycle, washing of membrane by using the back-flushing by water and air was applied. Filtered water accumulated in the tank was used for back-flushing while the air was supplied by the air-pump connected to the device. Any way of washing of the membrane did last for 30 seconds. On the base of filtration cycles, the effectiveness of membraned technology was evaluated.
3. Results and discussions
Sample of raw water was taken ahead of the membrane within every filtration cycle performed. Filtered water was sampled behind the membrane. Figure 3 to 5 present the turbidity progress in raw water and in filtered water and the difference in trans-membrane pressure over the filtration period (before and after washing of the membrane).

![Figure 3](image1.png)
**Figure 3.** Turbidity abatement process by using the ultrafiltration (water with a low turbidity) and difference in pressure before and after washing of membrane.

![Figure 4](image2.png)
**Figure 4.** Turbidity abatement process by using the ultrafiltration (water with a medium turbidity) and difference in pressure before and after washing of membrane.
Figure 5. Turbidity abatement process by using the ultrafiltration (water with severe turbidity) and difference in pressure before and after washing of membrane.

Under the act of washing by using the air and water, the membrane facing the lower turbidity level managed to get clean again and reached the features as it had in the beginning of the cycle. Higher level of turbidity caused that it was not possible to the membrane to regain the level of initial input pressures that the membrane had in the beginning of the cycle. Only after the turbidity level has been decreased and a few back-flushings has been performed, the initial level of input pressure has been regained. On the other hand, these trans-membrane pressures can still be considered as being very low, so it would be possible to prolong the filtration cycle.

4. Conclusions
Turbidity removal is the major issue at the WTP Jasná. Limit for turbidity 5 NTU is set by Decree No. 247/2007 Col. Measuring data provided that the turbidity level of water treated by using the ultrafiltration device are compliant with the legal limit for drinking water.

By using the ultrafiltration the decrease by 76,1% has been reached in the first experiment (average turbidity in raw water 1,55 NTU). The efficiency of turbidity removal was 95,2% that was reached by ultrafiltration of water with a higher level of turbidity (average turbidity in raw water 8 NTU). High effectiveness of ultrafiltration was reached also with the water with the turbidity 37 NTU. In all of the three experiments, the turbidity of treated water ranged between 0,37 – 0,38 NTU.

Ultrafiltration devices feature the high level of reliability, mechanical firmness of capillars and membrane modules compatibility. On a small built-up area, these devices are capable to provide a high filtration performance. Great chemical endurance of modules in a wide range of pH values represent a standard for chemical treatment performed in cycles. UF devices are nearly maintenance-free.

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