Water treatment plants with large stainless steel filters: New perspectives for the ozone biofiltration process

Ozone bio-filtration is an established process for treating surface water to obtain potable water. As a practical example, this report describes a new way of designing treatment plants using stainless steel filters manufactured at the site. In 2013–2014 an entirely new water treatment plant was erected in Norway to reduce the colour and TOC and to increase the hygienic safety of surface water obtained from a local lake. This plant has a maximum treatment capacity of 680 m^3/h, and its operation is based on the ozone bio-filtration process. The new plant has been in continuous operation since the end of August 2014 and supplies potable water in good quality to the network.

Ozone bio-filtration

In recent years, ozone bio-filtration has become established as a successful method in drinking water treatment applications. Practical examples in Germany, Scandinavia and the USA illustrate that with ozone bio-filtration it is possible to build reliable and economical drinking water treatment plants [1]. The NOM (natural organic matter) content is important in the case of water that is intended for the supply of drinking water. The NOM concentration is analytically calculated as the sum of the dissolved organic carbon (DOC). Typical DOC levels in waters are 3 to 6 mg/l. DOC levels up to 8 mg/l can occur in surface waters. In particular, the DOC levels from vegetable decomposition processes have a great effect on the colouration. Water with increased DOC levels should not be used for the supply of drinking water without water treatment. This is due to the fact that even supposedly stable water can experience a sudden and sharp increase in germs after oxidative water treatment (e.g. adding disinfectants). Ozone bio-filtration is a proven method for the treatment of water containing humic substances. Under the influence of ozone as a strong oxidation agent, the organic carbon compounds with a high molecular weight are split and the concentrations of the compounds with a low molecular weight are increased. Some of the compounds created in this way are biologically available and can be biologically degraded in a downstream bio-filtration stage.

Flåte water treatment plant

The Norwegian municipality of Bamble (Telemark) uses surface water from the inland lake “Flåte” to supply drinking water to approximately 12,000 people. The water is extracted at a depth of 28 meters. After water treatment, the water is pumped into a large tank elevated to approximately 85 m. The old water treatment facility comprised a simple preliminary purification stage using a plane sieve, disinfection by chlorination and water glass dosing to raise the pH-value.

Figure 1: New water treatment plant Flåte

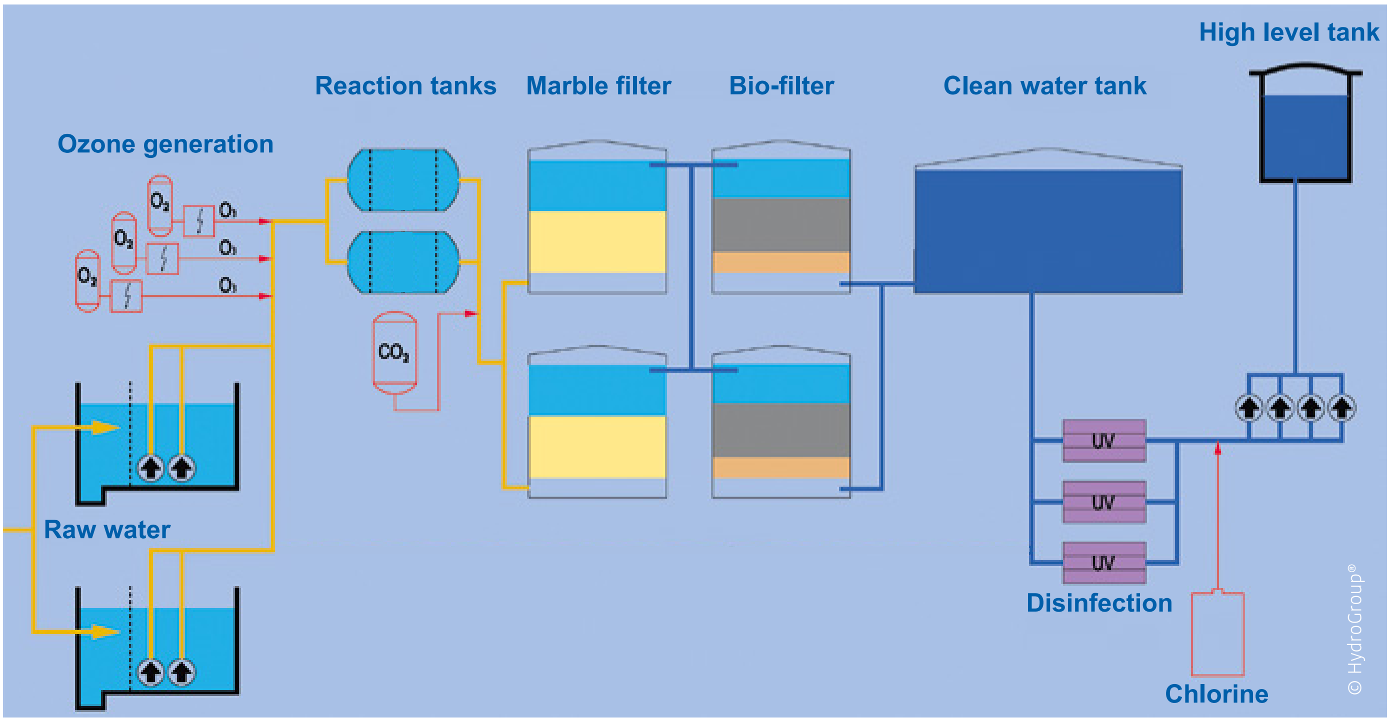

Figure 2: Principal treatment process

This was not sufficient to fulfil the Norwegian requirements for drinking water quality.

An entirely new water treatment plant (**Figure 1**) was built in 2013–2014 to reduce the colour and TOC and to increase the hygienic safety. The new system with a treatment capacity of 680 m³/h includes the processing stages ozonation – CO_2 dosing – marble filtration – bio-filtration – UV treatment – chlorination (**Figure 2**).

During the preliminary planning phase, the consulting office had looked into and compared different variants. A system made entirely of stainless steel components turned out to be the most advantageous solution. The system with two treatment lines comprises two horizontal ozone reaction tanks, two upstream filters with filter vessels made of stainless steel for hardening, two downstream filters with filter vessels made of stainless steel for bio-filtration as well as a large pure water tank, also made of stainless steel.

The primary reasons for deciding in favour of stainless steel included the distinctly shorter construction periods as well as the easily achievable high standards of design and safety in keeping with the calculated building costs. The latter is particularly important, as it was possible to complete the building structure during the summer months and install the on-site production facilities with the tanks and filters inside the building during the severe Norwegian winter.

In addition to the new construction, the existing power house was completely refurbished and integrated into the unit. This was carried out during on-going operation to ensure continued supply of water. The new unit with additional rooms for operation and monitoring is linked to the existing power house by means of a sealed pipe canal measuring approx. 3 x 3 m.

Ozone system

An oxygen generation unit and an ozone generation unit with ozone mixing system are also installed in the existing power house.

The ozone generation system (**Figure 3**) features a redundant design with three independent lines. Each of the ozone generators has an output of up to 1,000 g/h with an ozone concentration of 10 % (wt), which enables an ozone dose of up to 4.4 g/m³ water. The water-cooled ozone generators with a maximum power consumption of 10.8 kW each are cooled by an internal cooling water circuit. The heat is transferred to the cooling water flowing through the heat exchanger.

Figure 3: Plasma ozone generators with cooling systems

Figure 4: PSA systems

Figure 5: Venturi injection systems

Due to the high concentration of the mixture containing ozone and oxygen of 10 % (wt), only a small amount of oxygen is necessary. An oxygen quantity of 6.8 Nm^3/h per line is required for the maximum ozone output of 1,000 g/h per line.

The oxygen is generated locally by three PSA generator lines (**Figure 4**). Each line can generate a quantity of up to 6.8 Nm^3/h. As a result, complete redundancy is also ensured here. Oxygen is generated by concentration of the atmospheric oxygen with a purity of up to 93 %. Each generator line consists of a screw compressor unit (transport capacity = 1.50 m^3/min) with an integrated compressed air dryer, a compressed air tank with a capacity of 270 l, a PSA generator and an oxygen tank with a volume of 320 l. The oxygen is concentrated or enriched in the PSA (Pressure Swing Adsorption) generator with molecular sieves.

Each system consisting of three parallel treatment lines contains a highly effective ozone-mixing system. With ozone systems – in particular with high doses and lower temperatures – the mixing system is decisive for system effectiveness. Ideally, all the supplied ozone is mixed with the water, dissolved and completely consumed. Very high input levels are possible with Venturi injection systems (**Figure 5**). Mixing with the finest possible bubbles is imperative for an optimum mass transfer.

With the large number of small bubbles, the surface is maximised for the mass transfer. In this case the driving forces for the mass transfer are the concentration and particle pressure differences at the gas/water boundary surface. In addition to the spontaneous reactions in the area of ozone mixing, the subsequent reaction time also plays a major role. It is characteristic of reaction systems that the ozone content continually decreases in the direction of flow through the reaction tank as a result of ozone reactions and ozone breakdown.

The ozonised water is permitted to flow through the pipe canal into two parallel low pressure contact tanks made of 316Ti stainless steel with a length of 10 m and a diameter of 2800 mm. Distributor plates are welded at the inlet as well as the outlet of the contact tanks (**Figure 6**) to achieve a uniform plug flow.

Carbonic acid is added to the water after it is discharged from the contact tank and then an upstream filter containing calcium carbonate is employed to achieve the desired mineralisation, reduce the level of residual ozone in the water, and to hold back particles to relieve the following bio-filtration step. The alkaline upstream filters have a diameter of 5.50 m and a height of 7 m and work with an upstream velocity of 10–14 m/h, depending on the production flow.

Figure 6: Reaction tanks

Figure 7: Filter tanks

The ozonised and mineralised raw water flows through the filter overflow channel into the downstream bio-filter. The bio-filters, constructed as multi-layer filters, have a diameter of 6.70 m and a height of 7 m, and work with a maximum filtration rate of 8–10 m/h depending on the production flow. The gravity-driven filters have a layer of sand and a bio-filter layer made of expanded clay.
All filters are provided with compression-resistant nozzle plates and complete internal filter piping for the distribution of flushing air, discharge of backwash water and regulation of the filter overflow. Backwash is carried out on each filter every two to three weeks. The filter tanks (**Figure 7**) are fully sealed and are vented or aerated using special filtration systems. This prevents ozone discharge into the room.
The treated drinking water is stored temporarily in the 800 m^3 pure water storage tank (**Figure 8**) with a diameter of 13 m and a height of 6.3 m. The storage tank works as a source basin for the outlet pumps and the filter backwash pumps. The pure water is supplied through the pipe canal to the UV systems in the power house, chlorinated and then carried by pumps to the distribution system via large elevation tanks.
In the process hall, all system components required for operation can be safely accessed from the operator platform. Condensation on the stainless steel surfaces is prevented by climate control and the fact that the water-conducting systems are completely sealed. The ambient temperature in the operating areas is adjusted to the temperature of the water, as the large stainless steel surfaces serve as radiators or heat sinks.
The fully operational system has been running since the beginning of August 2014. The results so far have met expectations and demands. Plant operation is cost efficient, smooth and the system has not required any major maintenance.

Flushing water

The flushing water is fed back to a lagoon that acts as a retention basin with a connection to the raw water source. No further treatment steps for the backwash water are necessary, especially as no chemicals are required or used for this method of water treatment.

UV system

A UV system is connected as a second barrier. The UV system consists of three lines in total which are dimensioned so that two systems are sufficient for maximum operation. Each line is provided with a flow meter and a regulating device to ensure that the maximum permissible flow rate is not exceeded and that disinfection is always guaranteed. The minimum UV dose is 400 J/m^2.

Conclusions

Today's operating conditions feature an ozone dosage of 3.0 g O_3/ m^3 and normal water production of 500 m^3/h, which result in a retention time of 15 minutes in the reaction chambers and approximately 45 minutes empty bed contact time (EBCT) in the total filter volume. As a result, the colour is reduced from 22–25 mg Pt/l in the raw water to 5–7 mg Pt/l in the treated water, and the UV-transmission is increased from 72 % per cm to

Figure 8: Pure water tank

87–90 % per cm, which ensures the best conditions for effective UV disinfection and chlorination in the last treatment steps. The turbidity in the treated water is lower than 0.2 FNU, and the pH is stabilised at 7.5. The total TOC reduction is approximately 15 % (raw water 4.3 mg TOC/l, and treated water 3.7 mg TOC/l). By adding 0.7 g O_3/g TOC, approximately 17 % of the natural organic matter is chemically degraded to easy biodegradable fractions (BDOC) that can be removed in the bio-filters.

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