REMOVAL OF AMMONIA WITH BIOLOGICAL PROCESS IN THE TREATMENT OF DRINKING WATER

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Abstract

More than 128 wells for drinking water purposes in Hungary have higher ammonia concentration than the limit required in the Hungarian Standard (MSZ) for water quality. The situation in the 'Alföld' region is particularly bad. The main cause of the change in the water quality derives from physical, chemical and biological processes. The authors carried out several examinations during one and a half year in Csongrádi Country, Hungary, to develop a water treatment process for small villages having similar problems. They examined the polluted ground water containing iron, manganese, ammonia and the substances which come to existence after airation, such as microbiological materials. The purpose of the investigation was to remove these contaminants mainly ammonia by physical and biological processes.

Keywords: drinking water, biological filtration, ammonia.

Introduction

Organic contamination causes biological regrowth in the drinking water distribution system. Pilot plant was established to treat the water to prevent pollution of the network by biological substances. The purpose of the technology was to reduce the concentration of ammonia with biological process on filters and produce ammonia free water. The nitrification of ammonia went on in a three step filtration process.

Ammonia and nitrate both exhibit undesirable effects when present in water for potable supply. Ammonia can interfere with the chlorine used for disinfection of water. High nitrate levels can cause methaemoglobemia in infants and there has also been some suggestion that they may also give rise to the formation of carcinogenic nitrosamines in the stomach.

Nitrate occurs in both surface and groundwaters in Hungary and is associated with agricultural practice and the application of nitrogenous fertilisers. Nitrate levels in many underground resources rose as a result of increased use of fertilisers. The direct hazard to health has been demonstrated due to ammonia in drinking water. The World Health Organization European Standards recommend a level of not more than 0.05 mg/l in drinking water. The Hungarian Standard (MSZ 450/1–1989) recommends 0.1 mg/l for underground water. Ammonia must, however, be removed during water treatment to allow a free chlorine residual to enter supply for disinfection. This is almost always accomplished by the use of breakpoint chlorination which converts it predominantly into nitrogen.

The Biological Processes in the Network

The biological processes in the network can be characterised with the following steps:

Mineral salts Nutrient	⟶	Bacteria organic compounds (building of biomass)
Inorganic compounds Fe^{++}, Mn^{2+}	Iron bacteria ⟶ (autotrophs, heterotrophs)	Fe^{++}, Mn^{2+} Inorganic binding
NH_4^+	Nitrifying bacteria ⟶	$NO^{2-} \rightarrow NO_3^-$
Oxygen demand in the water	Airation ⟶	Bacteria in the network

Measurements

The first step of the investigation was the measurement of the existing network. The floating sediment was measured in several m^3 with filter candels under pressure at the end of the network. The pore size of the filter patron was 20–30 micron *(Fig. 1)*. The secondary sediment growth did not reach the allowed 1 cm^3/m^3 seston concentration only in few cases.

Microscope study proved (*Figs. 2,*) that the sediment consists of living- and dead iron- and manganise bacteria. Bacteria occurring the most often:

Crenothrix polyspora,
Clonotrix fusca,
Leptothrix ocraceae and
Gallionella feruginea.

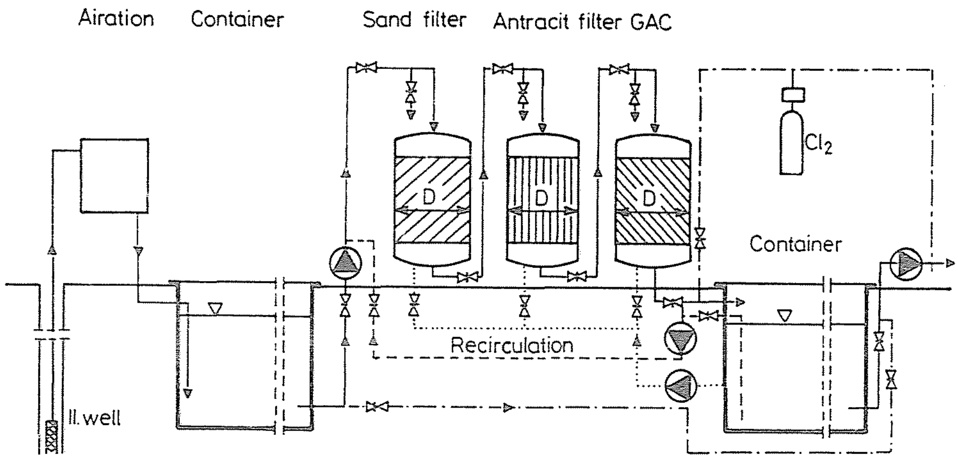

Fig. 1.

There were many polysaprob indicators on the surface of organic materials in the network:

Sphaerothilus natans,
Zoogloea ramigera,
Glaucoma sp,
Colpidium sp and
Vorticella sp.

One part of microorganisms is only a 'guest' in the network. They cannot accommodate themselves to biotop for longer time, so they die. Most of the microorganismm spend their life in the water distribution network and get the nutriments also from here. They can breed here, too. Finally, the indicator organisms can accommodate themselves to special circumstances.

Our intention was to remove the above mentioned substances with the treatment process. The first purpose was to remove ammonia and iron. In the examined case the ammonia concentration was high.

Removal of Ammonia

The opportunities for ammonia removal are the following:

- breakpoint chlorination,
- ion exchange,
- biological nitrification.

	1990.01.08.	1990.01.10.	1990.01.11.	1990.01.16.	1990.01.19.
Raw. water	1.4	1.27	1.53	1.22	1.49
Sand filter	1.17	0.99	1.52	1.14	1.48
GAC I. filter	1.4	1.14	1.52	1.17	0.8
GAC II. filter	0.08	0.74	0.15	0.17	0.01

Fig. 2. Reduction of ammonia after the filters

Breakpoint chlorination does, however, have the following disadvantages, not shared by a biological ammonia removal (nitrification) process:

- long contact times (over 1 hour) required at low temperature,
- interference from organic nitrogen compounds,
- formation of odorous nitrogen trichloride of dichloramine under certain circumstances (e.g. too high chlorine dose),
- production of trihalometanes and organochlorine compounds, particularly when the chlorine dose required is high.

Biological denitrification has certain advantages compared with ion exchange:

- it does not necessarily add undesirable constituents, such as chlorine, to the water, though a small residual of the added carbon source (e.g. methanol) may remain,
- the excess biological growth, produced as waste, is much easier and cheaper to dispose of than spent regenerant from ion exchange,
- the process is cheaper to install and operate than ion exchange.

The chief disadvantage of the biological process is the fall in the rate of denitrification at low temperatures. The process must be avoided from that.

The biological ammonia removal can be carried out with the following processes:

- biological filter,
- fluid bed reactors,
- rapid sand filters and
- microbiological activated carbon (BAC).

Ammonia Reduction with Nitrification

The biological oxidation of ammonia to nitrate occurs in two distinct oxidation steps: ammonia is oxidized to nitrite by Nitrosomonas and nitrite is then oxidized to nitrate by Nitrobacter. This process has often been treated as one-step reaction since ammonia oxidation is frequently in the rate-limiting step. However, nitrite accumulation has been observed in some processes, indicating that there are conditions where ammonia oxidation may not be rate limiting. Consequently, it is necessary to have a better understanding of the nitrification process as a two-step reaction. Nitrifying bacteria have long generation times. The low energy yield from the oxidation reaction results in a low cell yield. The organisms are sensitive to a number of environmental conditions, i.e., pH, dissolved-oxygen concentration, temperature and inhibition. Specifically, the role of the substrate, ammonia or nitrite, and the interrelationship between the Nitrosomonas and Nitrobacter were studied. The growth parameters for the two populations were determined using steady-state ammonia- and nitrite-oxidation data from suspended-growth-chemostat experiments. During the nitrification the ammonia disintegrates to nitrite then to nitrate with the help of Nitrosomonas and Nitrobacter.

$$55\ NH_4^+ + 76\ O_2 + 5\ CO_2 \xrightarrow{\text{Nitrosomonas}} C_5H_7NO_2 + 54NO_2^- + 52H_2O + 109H^+$$

$$NH_4^+ + 400\ NO_2^- + 5\ CO_2 + 195O_2 + 2\ H_2O \xrightarrow{\text{Nitrobacter}} C_5H_7NO_2 + 400NO_3^- + N$$

There are several bacteria participating in the process. In the ammonia – nitrite reaction take part the Nitrosomonas, Nitrosocystis, Nitrosovibro, Nitrosococcus, Nitrosospira and Nitrosolobus. In the nitrite – nitrate reaction the activity of Nitrobacter, Nitrococcus and Nitrospina are important.

Under the oxidation process from ammonium to nitrate the oxidation level of the nitrogen changes from –3-to +3. So it can be assumed that the oxidation process has several steps. Presumably hydroxilamine, hyponitrite, dihydroxiammonia, nitroxil, nitrogenoaxids and nitrohydroxiamine are present in the reaction. Intermediate compounds are unknown in the reaction of nitrite to nitrate so it must take place in one step. Most of the nitrifying bacteria are obligate autotroph, so the hydrogencarbonate plays an important role in the metabolism. If we describe these composites with 'C H NO' experimental formula, with the following reaction could be dyscribed the infiltration of inorganic carbon and nitrogen into the bacterium cells:

$$4\ CO_2 + HCO_3^- + NH_4^+ + H_2O = C_5H_7NO_2 + 5\ O_2$$

Pilot Plant

Several investigations were carried out to find the optimal treatment process.

The parameters of the wells are the following:

	I. well	II. well
Q (constant)	320 l/min	650 l/min
Storage	2 × 25 m	
Q (February)	280 - 300 m^3/d	
Q (August)	450 - 500 m^3/d	
Length of network	19.3 km	

It is important to mention the main water quantity parameters of the I. well. The nitrate concentration was very low.

ANALYSED COMPONENTS	PARAMETERS	
	I. well	II. well
Temperature	26 °C	29 °C
pH	7.73	7.9
Iron	0.22 mg/l	0.12 mg/l
Nitrite	0	0
Nitrate	0	0
Ammonia	2.12 mg/l	1.77 mg/l
Chlorine	42.93 mg/l	31.81 mg/l
Sodium	360 mg/l	294 mg/l
Potassium	5.4 mg/l	4.8 mg/l
Arsenic	0.037 mg/l	0.034 mg/l
Calcium	12.1 mg/l	7.8 mg/l
Magnesium	8.4 mg/l	3.2 mg/l
Methane	54.2 mg/l	41.85 mg/l

Multilayer filtration facility was applied on Fábiánsebestyén which was in operation after the wells.

The Treatment Process

Because of the even operation of biological film, the filtration period was chosen to be 7 days. It would be possible to operate with the rate of 4 m/h. Based on former investigations, the filtration rate has an effect on filter period. For safety reasons a parallel treatment line is required. In this case the backwashing of the filter is possible, while the other line is operating. Later, when the water demand increases the other line can operate permanently.

Because of existence of biological film, the water flow on the filters cannot be interrupted.The permanent hydraulic load is important because of nutrial supply. In case of minimum water consumption at night, the produced water is more than the consumption, therefore overplus quantity of water comes to existence in the clear water container. It is recommended to establish a recycling system, which starts to operate when there is no need to fill further water into the container.

To the nitrification process it was not necessary to implant filters, because the required bacteria were present in the raw water. They spread after 1–2 hours filtering. The process was operating at the dividing line of fast and slow filtration. The filter running time depending on the load was between 2–10 days.

Disinfection

The water in Csongrád region is also contaminated with humic and fulvic acid, ammonium, arsenic, etc. Under such circumstances disinfection with chlorine makes complications, for example trihalomethanes (THMs) are expected to appear in the network. For this reason treatment with chlorine is not recommended before removing the above mentioned substances.

Research work has been also carried out to find the most suitable disinfection process. It is well known that chlorination is not the best solution for disinfection water with high organic compounds.

Investigation of the possibilities of using UV-radiation and silver is promising for the prevention of network pollution, but under the described circumstances they have not been clarified yet.

Results

- The existing results of the one and a half year long experiences show that the treatment processes can produce appropriate water quality.
- The presence of ammonia makes bacteriological grow. The described network can be considered as a reactor where physical, chemical and biological processes are going on. These processes producing biological and other substances spoil the quality of water. The organic substances produced by nitrifying bacteria cause taste and odonr problems.
- In the first step only sand and hydroanthracite were used as filter materials. The decreasing of the chemical oxygen demand (COD) was hardly detected. Later the process was enhanced with activated carbon filter (GAC). The ammonia was successfully removed, the nitrite ion could have been detected only in traces. The concentration of nitrate ion did not reach in any time the concentration of 10 mg/l.
- The total germ number was measured continuously. As it is expected it grew remarkably because of the biological process on the filters. Because of this reason an effective disinfection process is required as last treatment.
- The gas removal from water had to be solved many times, because of safety regulations. The airation of water causes rapid bacteriological growth, decreasing the water quality very rapidly. The number of bacteria is increased by the high temperature of water. If the airation is not essential then it can be neglected.

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