

Drinking Water Quality in the Czech Republic

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Abstract

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The quality of water has to be controlled and monitored by drinking water suppliers during all stages of the treatment process from the water sources to the end of distribution systems. The research, performed in Czech Republic from 2006 to 2008, deals with the assessment of the affect of water tanks on the quality of water supplied to consumers, specifically from various points of view: microbiological, biological and physic-chemical changes in water accumulation. Also studied was the influence of the air on the quality of accumulated water (secondary contamination), the influence of the structural layout and hydraulic ratios. In the project quick screening methods (paddle testers and BART™ tests) were applied in the collection of water samples and scrapings from wetted surfaces of water tanks. The results of the contamination degree discovered in the course of the project solution will serve as basic data for a scale that should evaluate the degree of water tank pollution as well as for resulting corrective measures or optimisation of water tank cleaning. The recommendations of limits for a scraping sample are based especially on the microbiological parameters. Secondary air contamination plays an important role in maintains of biologically stable water. Based on the number of microbial contamination discovered water tanks will be categorised and methods of suitable measures to be taken will be stipulated, operation optimisation as well as cleaning (schedule, methods and frequency of cleaning). The water quality in a storage tanks depends on their maintenance, e.g., to prevent the plaster falling on water surface, the use of antifungal surface coatings (prevention the growth of fungi on walls), the use of ceramics surface of reservoir walls, dark conditions (no windows or blue sheets) in all technological units, the prevention of dust fall out, the selection of suitable air condition and special air filters.

Keywords: air contamination; biofilms in water tanks; building construction; drinking water quality; secondary contamination

At present, after a noticeable decrease in the water consumption, it is necessary to secure all preconditions for the desirable future trend in the quality development of the supplied water (AMBROŽOVÁ 2006; AMBROŽOVÁ & HUBÁČKOVÁ 2006). General health requirements concerning

drinking water, its modification and distribution, the objects and chemical substances coming into contact with drinking water, the water for outdoor bathing and bathing in swimming pools, lidos and saunas listing at the same time the basic sanitary requirements for the pools equipment, are stipu-

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lated in the act No. 258/2000 Coll., of the Ministry of Health, of preventing the leakage and spread of infectious diseases. Drinking water is defined as wholesome water that, neither by permanent consumption nor by usage, brings about any diseases or health disorders caused by the presence of microorganisms or substances affecting the health of people and their offspring by acute, chronic, or latent effects, and whose properties perceptible by human senses and quality do not prevent its consuming and usage for the sanitary needs of people. The whole character of water is stipulated by the sanitary limits of indicators, regulated to implement legislative instruments. Further, it stipulates all duties of the owner or administrator of public water mains, of the person who has marked a public well as a drinking water source, and of the person who is the producer of drinking water or provides its alternative distribution. The hot water supplied by the domestic hot water main may be produced only from drinking water. Since 2004, the Drinking Water Directive (DWD), Council Directive 98/83/EC on the quality of water intended for human consumption (replacing the Council Directive 80/778/EEC) have been applied to the full extent. The Council directive pays most attention to the parametric values of the substances contained in drinking water. The microbiological quality is less monitored and there is virtually no biological monitoring. From the medical point of view, the limit values are set according to the toxicological aspects. The sanitary requirements for drinking (and hot) water and the frequency and extent of inspections of drinking water, i.e. the observance of sanitary limits of microbiological, biological, physical, and chemical parameters of drinking water, are stipulated by the decree of the Ministry of Health No. 252/2004 Coll. For the efficient meeting of the so-called new direction of considerations in the sphere of waterworks engineering, regarding both the plans for providing safe drinking water (Water safety plans) and the hazard analysis and critical control points in the production (HACCP), or for the risk assessment and risk management approach, it is necessary to pursue a common aim. All parties interested, from the research, projections, up to the technological and network operations, must be concerned with the production of biologically stable water. And thus similarly in such functions of all facilities so that the required stability of water could not be enthreated. Only the biologically stable water prevents repeated proliferation of freely liv-

ing microorganisms and creation of mucilage and algal mats on the water tanks walls and in pipes of the distribution systems with all the undesirable consequences of those phenomena.

MATERIALS AND METHODS

Presentation of the project. In 2005, the research workplaces of T.G. Masaryk Water Research Institute – Public Research Institution, Institute of Chemical Technology in Prague – Department of Water Technology and Environmental Engineering and Czech Technical University in Prague – Faculty of Civil Engineering took part in the public tender of the National Agency for Agricultural Research and submitted a proposal for the project solution with the main priority given to the problem of the quality degradation of drinking water during its storage time. In December 2005, after the successful selection procedure and decision on the financial support of the research, the project solution was commenced. As mentioned above, its objective is to prevent the undesirable organoleptic defects of accumulated water that is further deteriorated due to the insufficient security of the facility functions.

Characterisation and importance of water tanks. The water tanks are necessary and integral parts of the whole system of the water supply. They have been made for the distribution of drinking water to settlements (villages and towns) either as independent sources or as parts of groups or regional water mains. They were designed according to the then valid projections of the constant growth of water consumption. Nowadays, in consequence of their huge accumulating volumes, large amounts of water are stored on the way between the water purification plant and the consumption area. Another factor influencing the quality of the supplied water is the smog that enters the water tanks through insufficiently air-proof ventilation, overflow outlets, and handling inlets. Hydraulic-spatial solution of the water tanks should comply both with the quantity requirements of the consumption area and with the quality requirements for the quality of the supplied water. The requirements applicable for the water tanks are those pursuant to the act No. 258/2000 Coll. as amended and to the regulation of the Ministry of Health No. 252/2004 Coll. as amended by the decree No. 187/2005 Coll., setting down the hygiene requirements for

drinking and hot water and the frequency and extent of drinking water inspections, and pursuant to the decree of the Ministry of Health No. 409/2005 Coll., on the hygiene requirements for the products coming into direct contact with water and for water treatment. Further, the water tanks should comply with the requirements as set in the CNS EN 1508 (75 5356) Waterworks engineering – requirements for systems and parts for water accumulation from January 2000, and in the ČNS 73 6650 Water tanks from July 1986.

The functions and character of water tanks operating are indisputably important for the assessment of the water tanks influence on the quality of drinking water supplied. It is necessary to consider physicalchemical, biological, and microbiological parameters, to define their share of influence on the changes of the accumulated water, and to decide on further procedure. Stipulating the degree of the individual partial causes of the changes in quality of the treated accumulated and supplied drinking water is necessary for drawing attention to the effective methods of minimising the creation of biological films and present biological life in the water tanks (LECHEVALLIER *et al.* 1987; LUND & ORMEROD 1995; HALLAM *et al.* 2001; SCHWARTZ *et al.* 2003). In order to implement the project in practice, it was necessary to conclude an agreement with the representatives of the selected water distribution companies. Further, a set of operating water tanks was chosen that are parts of public water mains and that became subject for the assessment by several parameters: the importance and function of the respective water tank, its location and size with regard to the supplied area, the structures and materials used as well as the methods of operation. Based on the parameters mentioned, the technical and hydraulic-technological assessment is carried out necessary for further procedure of the assessment and search for the possibilities of solutions of cutting down the water retention time in water tanks while preserving their full functions.

Localities. Within the framework of the technical character of monitoring, the size of water tanks is assessed in relation to the present water consumption in the given locality. At the same time, the researchers inspect the structural and technological versions of the facilities, taking into consideration the location of the inlets to and outlets from the consumption area, manipulations during the feeding and emptying of chambers, and

discharge of water. They assess the condition of the water tank, its lifetime and structural conditions, condition of all repairs and reconstructions. Also, they pay attention to the hydraulic systems of water flow in the water tanks and water exchange, and check the flow (question of dead ends etc.). In the case of additional chemical substances, they check the possibility of perfect mixing of water with the chemicals. Further, they study and solve the questions regarding the ventilation in water tanks, air admission, and air conditioning or even heating of the valve chamber. In physicalchemical monitoring, they monitor the quality of the accumulated water and assess it pursuant to the decree of the Ministry of Health No. 252/2004 Coll., as amended by No. 187/2005 Coll., they evaluate hygienic safety (total and free chlorine or any other disinfectant). In biological analysis, they monitor the water accumulated in chambers, the character of scrapings or biofilms (evaluation by means of microscopic and bacteriologic analyses). Further, they observe biological stability of the accumulated drinking water, they survey the effects of the surface materials characters of water tank wetted surfaces on the potential growth of microorganisms and biofilms creation. Another significant factor is the detection of microorganisms or particles fed through air contamination. The researchers check the representativeness of the collection area in relation to the water quality assessment in the whole water tank and the solution of the questions regarding the water losses and their minimisation in water tanks. It must be pointed out that the water tank inspections are carried out at the time before their cleaning and mud-discharge, so that the conditions of armatures and structures can be truthfully documented.

The localities are monitored throughout the whole vegetation period so that all seasonal influences can be recorded as well as their relations to the quality maintenance of the accumulated drinking water in accordance with the decree of the Ministry of Health No. 252/2004 Coll., as amended by No. 187/2005 Coll. For collecting the samples and monitoring, the researchers use standardised methods (Czech National Standards or ISO standards) or their modifications (quick screening methods). The biological assessment used is also significantly applied in the so-called biological audits of the water distribution systems, networks, technological lines and accumulations, and their results are often used as cogent arguments

for their reconstructions (ŘÍHOVÁ AMBROŽOVÁ 2007).

Biological stability of water and study of bio-films formation. The biologically stable water should contain so low concentrations of decomposable organic substances and mineral nutrients that the growth and reproduction of microorganisms (see the creation of biofilms in drinking water pipes and secondary reproduction of microorganisms in water) can be prevented even in favourable conditions (LEHTOLA *et al.* 2004a, b). In the case of biological instability of drinking water, the air contamination also plays a significant role. For the above-stated reasons, besides chemical, physicalchemical, technological, structural, and hydraulic features, also added to the project were the biological problems regarding the air contamination, creation of bio-films, and advance growth of the organisms attached on wetted walls of the water tanks coming from reproducing stages transported by water or air.

The questions of the biofilms creation and growth of attached organisms, their structure and characteristics are not properly treated in water-works engineering from the point of view of the legislature. As regards the methods of scrapings, attached organisms, and sediments collection, no definite method, quantification methods or data interpretation are available. Therefore, the researchers in the course of the project evaluated individual methods of the sample collection (CSN EN 25 667, ISO 5667, TNV 75 5941, TNV 75 7121). The collected samples of free water or scrapings are hydrobiologically (determining the microscopic count of organisms pursuant to the ČSN 75 7712:2005 and ČSN 75 7713:1998) and microbiologically assessed.

In the microscopic tests, the hyphae of micro-mycetes or fibres of iron bacteria are often found. Microscopic analysis cannot provide us with information on their vitality (NIEMI *et al.* 1982). Therefore, we added tests of biological activity (substantial information for the biological stability of drinking water). We applied the Hach Lange's BART™ tests in the project to define the vitality and quantity of iron bacteria. A sample of water is poured into a sterile manufacturer's test tube (50 ml); 15 ml of the sample is poured into another special test tube with the reagents in powdery form (according to the indicator). This test tube is sealed and then, according to the manufacturers instructions, is either shaken or not. The content is cultivated either in vertical or horizontal posi-

tions in daylight/in the dark. Each day, the colour of the medium is checked as well as the possible reactions, such as the creation of bubbles, sediment, or colour strips. The result of the BART™ test is an approximate number of bacteria CFU/ml, read from the diagram or colour reaction of the test. We recommend to carry out the monitoring of the presence/absence of physiological groups of bacteria (for instance iron, muciferous, sulphate-reducing, denitrifying and nitrifying, total aerobic, fluorescence pseudomonades) (ŘÍHOVÁ AMBROŽOVÁ *et al.* 2007).

We took into consideration all requirements for the preparation of selective cultures, laboratory instruments and requirements for laboriousness and execution of the cultivation techniques. Further, we were inspired by quick screening methods commercially provided for instance by Hach Lange company (available on their website is a catalogue, pg 71, listing all those methods). For collecting the scraping samples (as well as water samples), we applied the so-called paddle testers with defined sizes of paddles. Cultivation medium is pre-spread on the paddle by the producer (on both sides, reverse and front); it serves for catching two types of specific groups of organisms. For instance, on one side of the tester may be cultivated total aerobic bacteria and on the other side coliform bacteria, moulds, and yeast, or disinfection control may be carried out. The testers may be immersed in the water sample or imprinted directly on the surface to get a scraping. They are cultivated in dark at laboratory temperature or at 36°C, after 24 h, 48 h, and up to 5 to 7 days (depending on the assignment), the surface with the grown colonies is compared with the titre charts (10^* of the number of microorganisms).

Secondary air contamination. In the project, we focus also on the microbial control of the air in the water tanks and accumulation premises. In selected places, the Petri dishes are placed containing selective agar for the collection of micro-mycetes, moulds, and yeasts. Open plates are left for 15 min in the premises, then sealed and cultivated in laboratories. After a certain period of exposition (5–7 days), the grown colonies are assessed and evaluated under a microscope. Since the interpretation of such results is somewhat problematic (the volume of air exposed to the agar area in the uncovered plate), we are currently working on a more suitable methods of the samples collection and their assessment (principles and

methods of air sample collection, place and time of exposition, quantification and evaluation). An inspiration for the method of collecting samples (for instance by aeroscope) was the decree of the Ministry of Health No. 6/2003 Coll., stipulating the hygiene limits of chemical, physical, and biological parameters for indoor environment in residential premises of some buildings. When studying this decree, we may start not only from the choice of biological indicators but also from their limits.

RESULTS

Monitoring of biofilms

In the course of 2007, we collected another set of scraping samples in the localities visited for the second time during the project. This time, we collected the samples from more places – the bottom of the facility, both the left and right walls, the outlet and the column (if there was any, otherwise we collected from another place, at the inlet or we took a sample of the sediment, water etc.). Table 1 shows an example of the monitored locality. It is apparent that parallel monitoring of several places in one locality is reasonable.

Examples of discovered abioseston: corrosive products, precipitates of iron, lime nodules, sand, detritus, cellulose, textiles, remnants of plant tissue, starch, pollen grains, frustules and valves of centric and pinnate diatoms, exoskeletons of dinoflagellates (*Ceratium*), of thecamoebians,

remnants of exoskeletons and shells of rotifers and crustaceans, butterfly scales, bristles and sloughs of oligochaete worms. Examples of discovered bioseston: clumps of bacteria, iron bacteria (*Gallionella*, *Leptothrix*), hyphae and conidia of micromycetes (*Alternaria solani*, *Alternaria* sp.), dinoflagellates (*Peridiniopsis*), diatoms (*Cyclotella*, *Navicula*, *Fragilaria*, *Synedra*, *Tabellaria*, *Asterionella*, *Melosira*, *Aulacoseira*), chlorococcal algae (*Chlorella*, *Scenedesmus*, *Stichococcus*), euglenoids (*Trachelomonas* sp.), colourless flagellates, infusorians, amoebas, nauplii and imagos of crustaceans *Cyclops* sp., rotifers (*Cephalodella*, *Rotaria*, *Asplanchna*, etc.), nematodes.

Based on our extensive one-year monitoring and the results of hydrobiological and microbiological analyses, we arrived at the following recommendations of the limits for the scraping sample type (Table 1). In the case of DMO and ABUN parameters, it is worthless to determine their recommended limits since their levels are substantially affected by the method, place, and locality of the collection (including the operation and manipulation in the facility). What is more, the assessment of abioseston is done by a subjective method whose result may be overestimated by the examiner.

Biological audits and secondary air contamination

In order to provide a meaningful monitoring and the assessment and subsequent recommendations

Table 1. Results of microbiological and hydrobiological analyses of biofilms and recommendations of the limits for the scraping sample type

Locality	Microbiological parameters (titre)					Hydrobiological parameters		
	TB 36°C	TB 22°C	COLI	DIS	MI	VMO (org/ml)	DMO	ABUN (%)
Outlet	10 ⁴	10 ⁴	0	10 ²	0	100	800	> 40
Pole	10 ¹	10 ²	0	10 ²	10 ¹	0	0	10
Bottom	10 ²	10 ³	0	10 ²	0	0	1000	40
Right wall	10 ¹	10 ²	0	0	0	0	4400	20
Left wall	10 ²	10 ³	0	0	0	0	500	20
Recommendations of the limits	0–10 ²	0–10 ³	0	0–10 ²	0–10 ¹	0	worthless	worthless

TB – total bacteria, COLI – coliforms, DIS – control of disinfection, MI – micromycetes, VMO – vital microorganisms, DMO – dead microorganisms, ABUN – abundance of abioseston

to the operator of the water tank, we must focus on solving the problems of air contamination, not only on describing the existing condition but above all on their solution. In solving the problems with air contamination we may start from several years' experience in the audits by waterworks plants. Their experience is mentioned further in the text. The fact that secondary contamination of accumulated drinking water is important is also demonstrated by the defects discovered during a hydrological audit done by companies with the underground raw water resources. Unfortunately, the hydrobiological findings discovered in the accumulated drinking water do not appear in underground water. They get into the accumulated water secondarily. They include for instance starch grains, pollen grains, butterfly scales, birds feathers, plants and grass remnants, textiles etc. These particles may have an indirect impact on the quality of the accumulated water, may become substrates for other organisms or even a source of nutrients for other organisms in the food chain, which is what troubles us more.

Another example of the influence of the air contamination on the deterioration of the accumulated water properties in the surface layer and wetted walls in the upper part of the water tank (where there is a chance to collect a sample when the facility is in operation) is, for instance, one of the localities monitored during our year-long in-depth biological audit (Table 2). Despite the fact

that the facility had been cleaned, in such places where we could carry out inspections during the regular operation we did not record any visible improvement.

It is namely the air contamination that has its share in the deteriorated quality of the wetted walls as noticeable especially in this locality, see the comments to monitoring.

Common monitoring of the biological character of water and scrapings included also the question of monitoring the level of air contamination. Based on the above-mentioned reasons, we focused in the second half of the 1G58052 project on the problems of air contamination, method of its measuring, quantification of results, and problems of filtering materials.

Measuring of air contamination

For the needs of the monitoring and assessment of the degree of air contamination, we arranged an assembly of simple mobile equipment that enables to find out the degree of air contamination. For the assembly of the simple mobile equipment we invited colleagues from Hach Lange company. They selected and supplied a suitable power source and an air sample collection device (a kind of an air pump). We added some indispensable attachments and fixtures enabling to place the basins as well as paddle testers, sucking heads and tubes. We

Table 2. Sample of the localities monitored during our year-long in-depth biological audit

Date of sampling/ sample type	Parameters							
	VMO	DMO	ABUN	TB 22°C	TB 36°C	DIS	COLI	MI
	(org/ml)			(%)	(titre)			
V.07/water	2	0	1–3	10 ³	0	0	0	10 ³
V.07/biofim	100	100	40	10 ⁵	10 ¹	0	10 ¹	10 ⁵
VI.07/water	0	0	1	10 ²	0	0	0	0
VI.07/biofilm 1	0	0	20	10 ⁴	10 ²	0	10 ²	0
VI.07/biofilm 2	0	0	40	< 10 ¹	<10 ¹	0	10 ²	< 10 ¹
VII.07/biofilm 2	8	0	20	10 ²	10 ¹	0	10 ¹	0
X.07/water	0	4	3	10 ²	10 ¹	0	0	0
X.07/biofilm 1	0	0	20	10 ³	10 ³	0	10 ⁴	0
X.07/biofilm 2	0	0	20	10 ⁴	10 ⁵	10 ¹	10 ⁴	10 ¹

TB – total bacteria, COLI – coliforms, DIS – control of disinfection, MI – micromycetes, VMO – vital microorganisms, DMO – dead microorganisms, ABUN – abundance of abioseston

tested the equipment in the accumulating tanks in operation and at the same time used it for finding out the effectiveness of various filtering materials mounted over the vent hole. For the specific purpose we chose 6 filter layers (pursuant to the EN 1508) represented by active-carbon air filter and 5 geotextiles. Each material was tested separately.

An inspiration for the method of samples collecting (for instance by aeroscope) was the decree No. 6/2003 Coll., stipulating the hygiene limits of chemical, physical, and biological parameters for indoor environment in residential premises of some buildings. A suitable proposal of a filter unit was another step in our monitoring. This unit was gradually mounted in ventilation holes in the accumulation area. The air ventilation unit designed by ECO Aer is adjusted so that it is easily applicable into various diameters, units or areas. For the sake of simple manipulation, we chose the plastic version of the tube type that enables not only the mounting of separate inter-stage elements of filtration but also an easier manipulation in the exchange of filters or actual mounting into selected premises. The filtration unit consists of six separately mounted filter units of defined filtering area, covered by two grids and fixed in a frame into the wall.

DISCUSSION

Gradually, we applied quick screening methods for the collection of water samples and scrapings from the wetted surfaces of water tanks (in operation and during unavailability times due to cleaning). The advantage of those methods resides not only in the manner of collection but also in the fact that a sample is imprinted directly on the surface of the cultivation medium on which the approximate number of microorganisms is regularly read after a certain cultivation period. The results of the analyses carried out with the use of paddle testers or tests of biological activity have informative nature and are fully sufficient for subsequent manipulations in water tank premises. The results of the contamination degree found in the course of the project solution will serve as basic data for a scale that should evaluate the degree of water tanks pollution as well as for resulting corrective measures or optimisation of water tank cleaning. We must point out that the paddle testers with the collected organisms were compared with the

cultivation techniques. As early as today we may state that the plausibility of the screening assessment is considerably high. For finding out the extent of contamination in water tanks, we used the following indicators: total aerobic bacteria (may be cultivated at 22°C and 36°C), yeasts and moulds, disinfection control, and coliform bacteria. Based on the discovered number of microbial contaminations we will categorise the water tanks and stipulate the methods of suitable measures adoption, operation optimisation as well as cleaning (schedule, methods of cleaning and frequency). The results obtained with the microbiological indicators will be assessed and compared in the course of the project solution.

By reason of the possible water contamination (by air, dust, insects or other animals), it is essential to secure the inlets and equipment designed for ventilation. In the case of holes right above the surface of drinking water, the holes must be adjusted to prevent the penetration of foreign particles from the outside. A suitable solution is the mounting of unwoven filter textiles or geo-textiles into all ventilation and suction holes. Once or twice a year or as often as needed is it necessary to replace the filters with new ones (presumably during regular cleaning of the accumulation facility). Further, we recommend microscopic and bacteriological checks of the textiles used. Textiles exchange is recommended after of the water tank cleaning. At present, we cooperate in mounting the filters in the selected ventilation areas.

Project outputs should serve as the groundwork for the amendment of the ČSN 73 6650. All results obtained in the course of the project are consulted with the representatives of waterworks plants.

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