Risk Analysis in Drinking Water Accumulation

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Abstract

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Drinking water is safe water, from the perspective of long-term use is does not cause any disease, pathogenic and hygienically unsafe microorganisms do not spread in it and customers enjoy its consumption. Drinking water is regarded as a foodstuff, therefore the known HACCP system can be used in the control system which can be applied not only directly to the final product, but also to the whole system of drinking water production, distribution, and accumulation. Even if there is no problem concerning the water processing and the technological line is well adjusted, the quality of drinking water is subsequently deteriorated by its transportation and accumulation. The condition and character of the operated distribution network and reservoirs are significantly and substantially related to the maintenance of the biological stability and quality of drinking water. This is well confirmed by biological audits of the distribution networks and water reservoirs. A significant fact is the negative influence of the secondary contamination by air in the reservoir facilities and the occurrence of microorganisms (fungi, bacteria) in free water and in biofilms. The findings obtained in the framework of biological audits were so alarming that the outputs of biological audits contributed to the reconsideration of the efficiency of the standard for the construction and design of water reservoirs and pointed out the necessity of its review.

Keywords: biological stability of water; HACCP system; microorganisms; safe drinking water supply; water reservoirs

The recommendations for the quality of drinking water, issued by the World Health Organisation (WHO) and The Bonn Charter for Safe Drinking Water (Kožíšek 2005), are currently substantial documents in the water supply which are gradually implemented in the water supply companies (IWA 2004 in Kožíšek 2005). The purpose of these documents is the trouble-free supply of water from the source to the citizens. The concept of the documents includes the system of securing safe drinking water, concerning particularly the health criteria, plans to secure safe drinking water, and independent regulation. Water Safety Plans (i.e. plans for safe water supply) are significantly founded on: (*i*) risk assessment within the whole system (from the source up to the consumer's tap); (*ii*) identification and monitoring of the check points most efficient in the reduction of

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the established risks and (*iii*) creation of effective management control systems and operation plans (these concern the routine as well as uncommon operation conditions). As far as the check-up of the drinking water quality is concerned, for the sake of these plans the methods, procedures, and tests can be used which supplement the common procedures of the operation monitoring. Mostly such methods are concerned which can establish whether the drinking water supply is in agreement with the stipulated parameters of the regulation of the Ministry of Health No. 252/2004 Coll., eventually whether a reassessment of the whole system is necessary. From the biological point of view, the microbial quality of water is monitored which is founded on microbiological testing comprising mostly the determination of the presence of faecal indicator microorganisms (event. the direct estimation of a specifically pathogenic, conditionally pathogenic or hygienically important microorganisms). According to the experience in the implementation of the complex audits of the water supply systems, it is highly important to introduce the monitoring of the microscopic picture as well to comprise the presence of the microorganisms which are not established in the microbiological testing, and further it is necessary to add that the microscopic findings (confirmation, establishment, determination) can be realised in a substantially shorter time interval (Davison *et al.* 2005).

In this system, the risk analysis (HACCP) can be applied which should take into consideration the whole supplied area including the sources of raw water, reservoir facilities, water processing (technology), distribution network together with the objects placed in it (pumping stations, accumulations, reservoirs) and the terminal points of the network at the consumers'. Based upon the establishment of the risk points, an appropriate plan for securing the safe water supply is designed subsequently. The plan is instrumental not only in the solution of emergencies, but also in remedial measures, preventive measures, common control, and eventually in ongoing monitoring and verification (e.g. audit mostly carried out by an independent subject) (Říhová Ambrožová *et al.* 2008, 2009).

MATERIALS AND METHODS

Safe and sound drinking water. Drinking water in the whole supply system will be safe only if the contamination of water sources is prevented, water is sufficiently processed (contaminating materials present are completely, event. partially removed and the limits fulfil the requirements for the quality and safety of drinking water), and any secondary contamination during the accumulation, distribution, and manipulation of drinking water is prevented (Říhová Ambrožová & Říha 2008; Říhová Ambrožová 2009). Long-term monitoring of the water supply systems through biological audits has pointed out the necessity of the solution of the negative secondary manifestations of water contamination (biofilms, evidence of the presence of organisms and particles). Biofilms have a significant influence not only upon hygienic safety of the supplied water, but also upon its organoleptic characteristics and corrosive aggressiveness. The seriousness of the microbial biofilms is mainly based upon the possible occurrence of pathogenic or conditionally pathogenic organisms.

To keep the quality of the produced drinking water in agreement with the limits of the regulation No. 252/2004 Coll., it is necessary to control regularly the quality of the water accumulated in reservoirs and that supplied by pipes as well as to maintain these transportation and accumulation systems by means of suitable treatments. On this ground, cooperation is important as well between the technologist of the water processing and the operator of the distribution networks including the facilities placed on it.

Distribution network as a risk point of the water supply system. Monitoring of the biofilms formation by the method of orientation screening (hydrobiological analyses of the scrapings from the exposed testing glasses fixed in specified profiles of the supply system) based on the microscopic quality analysis aimed at the indication of the established species of organisms proved to be a suitable control method for the assessment of changes in water quality during the transportation from the water treatment plant to the point of destination. Already after a sixty-day exposition, it was possible to prove different undesired effects upon the quality of the transported water according to the composition and frequency of the present particles of abioseston, eventually also according to the finding of living microorganisms. In the samples, the change of qualitative and quantitative presence of microorganisms and particles of abioseston was evident depending on the season of the year. The most frequently present microorganisms were diatoms of the genera *Cyclotella*, *Cymbella*, *Fragilaria*, *Gomphonema*, *Navicula, Nitzschia*, *Surirella,* cryptomonads of the genus *Cryptomonas*, green algae of the genera *Scenedesmus, Stichococcus*, filamentous green algae *Ulothrix zonata, Spirogyra* sp., cyanobacterium *Phormidium* sp., colourless flagellata, infusoria *Vorticella convallaria*, testacea and rotifer of the genus *Cephalodella* sp. Of abioseston, there were mainly corrosion products, precipitates of iron and manganese, detritus, flake formations, plant fibres, pollen grains, cellulose, starch, frustules of diatoms of the genera *Surirella*, *Meridion*, *Pinnularia*, *Nitzschia*, *Gomphonema*, animal remains (feathers, shells, bristles). Further, there were mycelar formations, conidia and micromycete hyphae, micromycetes of the genus *Tetracladium*, ferrous bacteria of the genera *Gallionella, Tolypothrix*, cysts of protozoa (testacea, infusoria etc.). From the composition of abioseston some assumptions can be drawn which need to be interpreted also together with the results of chemical and bacteriological analyses and eventually the optimisation of the water pipelines operation can be proposed, mainly the frequency of their desludging (Ambrožová *et al*. 2003; Ambrožová 2006). One posible explanation of the supply of particles and the occurrence of microorganisms in a distribution network is non-securing of the reservoir facilities against the secondary contamination during water accumulation.

Water reservoirs as a risk point of the water supply system. Every construction presents an element of risk for the purpose it has been established for. Water reservoirs are an element of water accumulation and an element which secures the pressure stability of the supplied area. As constructions, the reservoirs have an irreplaceable position in the water supply system and take an important part in the reliability of the whole, its sustainability as well as vulnerability. As constructions, they are strategically important, have a possibility of influencing the water quality, and their location plays an important role in the economic costs of the operation of the whole water supply. From the viewpoint of the operation of the reservoir facility, it is necessary to divide the construction into the constructional and technological parts. For the sake of analysis of the possible risks and their limitation (or reduction), it is necessary to identify them (Říhová Ambrožová 2009).

In the plans of the safe water supply, the distribution network is assessed as a whole, the monitoring of the reservoirs is rather less refined. Much better and more erudite is the processing of the case studies within the project *WaterRisk* where the reservoirs are considered as one of the principal parts of the water distribution subsystem (Tuhovčák *et al*. 2009).

Should the water supply from the source to the consumer be an efficient system, then the reservoir is necessarily a functionally indispensable and indivisible part of this system. If the water supply system is assessed as a whole, the monitoring of the reservoir facilities should be included as well (Říhová Ambrožová *et al*. 2009).

RESULTS

Situation and condition of drinking water accumulation in the Czech Republic

The aspects of the complex assessment of the influence of a water reservoir upon the quality of accumulated and eventually further transported water were solved by the project 1G58052 supported by the Ministry of Agriculture of the Czech Republic Project "Research into Degradation of Drinking Water Quality during Its Accumulation" in cooperation with the operator organisations. The influence of the reservoirs on the quality of water transported to consumers was assessed from the viewpoint of microbiological, biological, and physical-chemical changes taking place during water accumulation, from the viewpoint of the quality of the accumulated water as influenced by air, and from the viewpoint of the influence of the construction lay-out and of hydraulic relations on the quality of the accumulated water. To secure the meaning of the individual recommendations, the facts were also taken into consideration which had been established in the facilities during their operation and systematically monitored (mainly by means of a complex biological audit).

During the visits to the facilities, mainly at the time before their cleaning (condition of emptied accumulation tanks), photographic documentation of their current condition was made out, the construction and materials used, streaming hydraulics, delay time and, last but not least, instructions for the operation of the reservoirs were assessed as well. During the biological audits, it appeared that the unsuitability of inlet and outlet solution in one place, use of unsuitable construction materials, unsatisfactory surface finish of floors, free, unprotected penetration of air into the accumulation tanks, clear windows and door panels directly in the accumulation tanks, eventually completely missing doors and barriers separating the accumulation space from the fitting chamber, and the secondary contamination by air (repeated occurrence of micromycetes in biofilms and the assumption of the negative influence upon the safety of drinking water) are substantial for the deterioration of the accumulated water quality and biofilms creation. In testing the level of air contamination in the reservoir facility, there arose the necessity to tackle the secondary contamination by air streaming through vents into the facility by fixing suitable filters. In some instances, biological analyses indicated unsuitable maintenance and operation of the reservoir facility as well.

Based on facilities monitoring, the technical recommendation I-D-48 Constructional lay-out, operation and maintenance of reservoirs was processed which specifies in greater detail the risk points together with the recommendations for the facility operators. Substantial and fundamental is the fact that the processed technical recommendation became a basis for the revision of the suitability of the standard ČSN 73 6650:1985 – Reservoirs which applies to the projection and operation of reservoirs (ground as well as tower ones which are part of public water pipelines for drinking water supply). Considering the fact that this standard has already become obsolete and has also been incorrectly applied in some cases, its review has been recommended. The content of the current, practically proved standard remains preserved, the review itself is aimed at the specification of some articles of the standard, supplementation with new methods, and ways of securing the reservoir facilities and their proper operation. Changes and amendments have been carried out in terms of practical results from the solved project and realised audits of water supply companies (Říhová Ambrožová *et al*. 2008, 2010).

Proposals to reduce risks

(*i*) As far as securing the facility is concerned, it is necessary to respect the requirements of the protective zone around the reservoir facility with the prohibition of entry and measures of the enforcement. The solution is in securing the fencing around every reservoir, eventually using a camera system or another alarm system. This includes a regular control and maintenance of the immediate surroundings of the reservoir as well. On principle, greenery is not planted and airborne vegetation is removed. Necessary is also to prevent any unsuitable use of the reservoir (and particularly the fitting chambers) because, according to the practical experience, its cleaning and in some cases indiscipline of the operating staff appears problematic.

(*ii*) To determine the regular check-ups of the reservoir condition (excluding common visits during water sampling) and, according to the current condition of the reservoir, to retain or increase the number of the regular check-ups of the facility condition. Of course, this decision is individual and it depends on the operator's consideration. During these check-ups, it is important to record the conditions and characters of the constructional parts of the facility, i.e. bottom construction, supporting structure, roofing, entrances, staircases, ladders, floors, doors, gates, rainwater pipes. Another example of the control is an independently realised biological audit which refers to some aspects (accumulated water directly in the tank, scrapings from wetted tank walls) which are not referred to by generally carried out analyses of water at the inlet/outlet into/from the tank. The operating staff (event. other persons authorised to enter the facility) should be equipped for the entrance into the accumulation tanks of the reservoir in agreement with the Hygienic minimum for water supply workers (Kožíšek *et al*. 2006).

The protocol on the biological audit processing should include the following information: basic data on the condition and operation of the monitored facility (locality; reservoir type; location; terrain; source; distance from the water treatment plant; number and size of accumulation tanks; frequency of change of water; number of monitored tanks involved in audit) and the appearance of the facility. It is recommended to make out photographic documentation and to record the actual condition of the facility. The character of the facility condition and its situation in the terrain is substantially reflected in the eventually established defects of the biological character as well (secondary contamination etc.). As supplementing data, information can be obtained referring to the inlet and outlet, method of water treatment, cleaning and its process, and eventual reparations and reconstructions. Biological analyses take an essential part of the biological audit. The protocol is established separately for water samples and scrapings. It is appropriate to record the process of sampling into the protocol, e.g. in this case the water sampling with a special sample container from the surface layer of 15 to 20 cm depth and the scraping with sterile plastic foam bands or the imprint by paddle testers. In microscopic recording, it is recommended to make photographic documentation and thus to get also a view of the whole coverage of the visual field of the microscope, to record "unsafe" microorganisms and to keep the photographs "at the store" in case of controversial results and data archiving. A summary evaluation and a commentary on the established biological findings are appropriate as well. Within the biological audit, it is recommended to monitor the locality with the frequency of 4 tests during a year so that seasonal conditions could be rendered (spring, summer, autumn and winter). The output of the biological audit should be a summary of the results of biological analyses. In this relation, a summary evaluation of the biological findings from the complex monitoring of the locality during one year is recommended. Some established biological defects relate to the improper technical condition of the facility (including the operator's care), it is also advisable to record this fact. Further, the evaluation follows of the facility condition and the final recommendation. The evaluation of the facility condition and its eventual negative influence upon the condition of the accumulated drinking water are stated here. It is appropriate to mention the eventual recommendation for the removal of the defect, event. a proposal for the reconstruction as well (Říhová Ambrožová 2009; Říhová Ambrožová *et al.* 2009).

(*iii*) It is important to determine the requirements for the operation of the water reservoir in agreement with the methodology WSP, HACCP (IWA 2004 in Kožíšek 2005; Davison *et al.* 2005) and Hygienic minimum for water supply workers (Kožíšek *et al.* 2006). Here, the adaptation of crumbling floors is concerned and it is necessary to treat them so that they should be dust-free. The adjustment of floor surfaces is fundamental not only for eliminating dust in relevant spaces, but also for enabling easier cleaning (floors which could be cleaned by water and cloth, e.g. ceramic tiles, levelling cover etc.).

(*iv*) To check and adjust entrances, windows and ventilations in the reservoir constructions, to provide ventilation holes against foreign materials and insects intrusion, to procure sealing doors which will protect the entrance room or the manipulation chamber from intrusion of dust and air fallout from the surroundings of the water reservoir. And especially to check and adjust the windows and ventilations of the manipulation chambers and the accumulation tanks themselves.

(*v*) Necessity to solve the problem of the secondary air contamination (air and dust fallout) in the manipulation and accumulation spaces. In the case of their mutual interconnection to prevent the indirect pollution of the accumulation tanks. The solution resides in the securing of the dust-free environment in the manipulation chamber and, at the same time, the prevention of increased humidity in the manipulation chamber (increasing corrosion). Further, it is recommended not only to fit the ventilation holes with grids against snow and rain, but also to mount simple devices (frames with filtering fabric) which can be easily exchanged or filters with filtering fabric supplemented with carbon filters or filters saturated with active carbon. The choice of protection is given by the importance of the water reservoir and the possibilities of the operator organisations. During the project solving, the proposed filtering unit (Eco-Aer®) was adjusted so that it could be simply applied to any diameter and space in the facility wall. The filtering unit is composed of six independently fitted filtering units with known filtering area, covered by two grids and mounted by means of a frame into the brickwork wall. With the aim of minimisation of the insect intrusion and input of larger particles by air, the outer part of the filtering unit is fitted with a net grid and the inner part is fitted with a protective grid (this grid enables fixing other filtering layers and better manipulation during their exchange and fitting). The fitting of this unit minimises the extent of air contamination of the accumulation (event. also manipulation) tank. The efficiency of the filtering unit to eliminate dust particles, pollen grains, starch, plant fibres as well as other particles of abioseston was tested directly in the facility. Not negligible is its meaning in the elimination of the number of micromycetes in the air above the surface of the accumulated drinking water. This can contribute to the elimination of hyphae and conidia of micromycetes from biofilms and sediments. In some cases, the typical mouldlike smell disappeared from the space as well. Obvious is also the elimination of pathogenic fungi. The microscopic sample analyses of the scrapings from the wall of both right and left accumulation tanks during the operation, after some time from filtering set fitting, confirmed the absence of hyphae and conidia of micromycetes, abioseston being represented by corrosion products and iron precipitations, sand, plant fibres, and frustules of diatoms (Říhová Ambrožová & Říha 2008).

(*vi*) The timetable is set for the water reservoir cleaning in the dependence on its the condition, i.e. different firm sediments, e.g. deposits and incrustations from water pipes, from reparations of eventual defects of water pipes, from the precipitated and deposited materials from water etc. It means that in practice individually assessed are the reservoir condition, quality of supplied water, securing of inlets and openings, character of the biofilms created on the walls (in using quick screening methods, paddle testers, biological activity tests, ATP tests etc.). The operator also determines the process of cleaning and disinfection of the water reservoirs.

DISCUSSION

Presently, many investments take place being financed from different national as well as European sources. The ground of these actions and plans is mostly the bad technical conditions of these facilities or more strict requirements of the current legislation. On the ground of future investment costs as well as a broader view of securing the quality of the produced and distributed water according to the regulation of the Ministry of Health No. 252/2004 Coll. (as amended), it appears to be necessary to proceed also to their reconstruction (exchange, sanitation).

At this stage, it is recommended to carry out a biological audit which would be realised completely so as to establish not only the condition of the accumulated drinking water and the character of the wetted walls, but at the same time also the eventual influence of the secondary contamination by air. The samples properly taken can, in some cases, also discover defects of the constructional nature which play an important part in the deterioration of the accumulated water. An accurately aimed biological audit refers to some aspects (accumulated water directly in the tank, scrapings from the wetted walls of the tanks) which are not referred to by the analyses of water generally carried out at the inlet (outlet) into (from) the tank.

The scrapings from the wetted walls of the accumulation tanks and the samples of the accumulated water indicated defects of biological character. From the biological point of view, it is therefore necessary to determine the seriousness of the individual partial causes of the changes in the quality of the accumulated and further transported drinking water in relation to the creation of biofilms, and to minimise efficiently their creation and present biological animation in the water reservoirs. The present microorganisms can be released from the biofilms into the water thus deteriorating its quality. In many cases, biological analyses confirmed a decreased level of disinfection of the walls and the presence of indicators of the faecal pollution, further also the presence of indicators of the organic pollution and a not negligible number of micromycetes. The hydrobiological and microbiological analyses proved a substantial influence of the secondary air contamination upon the creation of biofilms on the wetted walls in the surface layer of the tanks. The quality of the accumulated drinking water is handled by monitoring the basic hygienic biological indicators stated in the regulation No. 252/2004 Coll. (as amended), nevertheless, despite the importance of the biofilms creation and their possible negative influence upon the accumulated water quality, no legislative regulation has been available so far. It would be advisable in the future not to neglect the importance of biofilms on the wetted walls in the facilities with the accumulation of drinking water.

CONCLUSION

We should pay more attention to the system of production, transportation, and accumulation of drinking water. The water quality can be influenced from within as well as from without at any point of the continuous system of the water supply. The risk points are the water reservoir facilities where the influence of the construction character and unsuitable operation of the facility (including security) prove to be negative. The reservoirs should be oases with refreshing water possessing detoxicating and regenerating effects. Water must be pampered because even water itself has its own memory. The intensification of the research, education of specialists, and development of an operational control system in the water supply are a good advertisement for the final product – drinking water. And it is up to us in which way we inform the public about the quality and safety of this liquid, may it be "only" water.

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