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Water, Wastewater and Energy in Smart Cities

Drinking Water Supply without Use of a Disinfectant

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Abstract. The paper focuses on the issue of drinking water supply without use of any disinfectants. Before the public water supply network operator begins to consider switching to operation without use of chemical disinfection, initial assessment should be made, whether or not the water supply system in question is suitable for this type of operation. The assessment is performed by applying the decision algorithm. The initial assessment is followed by another decision algorithm which serves for managing and controlling the process of switching to drinking water supply without use of a disinfectant. The paper also summarizes previous experience and knowledge of this way operated public water supply systems in the Czech Republic.

1 Introduction to the issue

Objective of the public water supply systems operators is to supply drinking water to the consumers in the required quantity and quality to meet the requirements stipulated by the Decree No. 252/2004 Coll., which sets drinking water limits in the Czech Republic. By applying the chlorine-based chemical disinfection and maintaining sufficient residual chlorine concentration in the distribution network, combined with other measures and actions, drinking water supply in the required microbiological quality should be ensured. However, research and experience from practice bring many new insights into functioning of the chlorine-based chemical disinfection. They show its negative aspects, mainly undesirable affection of taste and smell and occurrence of the so-called disinfection by-products. These disinfection by-products and the negative public approach to chlorine in water have prompted several countries, in particular the Netherlands, Switzerland and Germany, to gradual transition to drinking water supply without use of a chlorine-based disinfectant that remains in water as the residual disinfectant.[1, 2, 3, 4] In these countries, public water supply network operators rely on the adequate number of security barriers protecting the system from microbial contamination from the outside environment. If the number of barriers is sufficient, water can be distributed without any disinfectant. [1, 3, 4]

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1.1 Multi-barrier approach

Concept of more barriers (multi-barrier approach) ensures safety in case of failure of any of these barriers. The barriers include protection of the water source, multiple steps in water treatment and proactive management of the distribution system. When it comes to the question whether or not chlorine is irreplaceable in drinking water for human health protection, it can be noted that there are relatively little data confirming that the residual disinfectant in the distribution network would prevent outbreak of infection from drinking water. [2]

The text below describes individual problems that may arise at the water source, in the water treatment plant and in the distribution network that could prevent operation without a disinfectant. This may include, for example, insufficient water source protection, inadequate water treatment due to raw water quality, poor technical condition of the water treatment facility (unprotected air filtration, absence of thresholds under the storage chamber door, etc.), water leakage in combination with vacuum events, etc. The process of initial assessment of the water supply system is shown in the form of a decision algorithm, see Fig. 1. [1, 3, 5] The assessment also includes simulation of chosen indicators of drinking water quality in the water supply network. [6] The initial assessment is followed by the transition strategy extended by defining possible undesired events and their factors which can occur after immediate discontinuing chlorination. Three major undesired events have been defined. For determination of the undesired events and factors, the WaterRisk general methodology [7] has been used.

2 Advantages and disadvantages of drinking water supply without a disinfectant

2.1 Advantages of drinking water supply without a disinfectant

Advantages of operation of the water supply network without use of chemical disinfectants are as follows:

1. By-products of disinfection, such as carcinogenic trihalomethanes (THM), do not occur in drinking water. Halogen phenols, resulting in customer complaints about chlorine flavour and chlorine odour of water, do not occur either. For example, omission of chlorine dosing in Amsterdam led to reduction of THM value below the limit of detection. [1]
2. Masking of microbial contamination of the drinking water cannot appear, as documented during operation with application of a disinfectant. When the disinfectant is used, even very low concentrations of free chlorine cause inactivation of the indicator coliform bacteria and E. coli, as these organisms are very sensitive to chlorine. For instance E. Coli is reduced by 99 percent as early as at the concentration of 0.05 mg $\cdot$ l^{-1}. [8, 9] After addition of the disinfectant, these indicator organisms may be inactivated during the contamination event, whilst the other, more resistant pathogens may still be present. [1]
3. The disinfectant can react with biofilm (material, biofilm material), but cannot react with bacteria. The disinfectant residue can support re-growth, namely by reacting with organic compounds contained in water and producing more readily biodegradable compounds. [1] During common operational conditions the biofilm is stable and the biomass exchange between the biofilm and flow of water is balanced. If the equilibrium is violated due to e.g. rapid changes in the hydraulic

conditions or disinfectant concentration change in the network, the biomass may be revealed from the biofilm which increases the amount of biomass in the drinking water. [10, 11]

2.2 Disadvantages of drinking water supply without a disinfectant

Disadvantages of operation of the water supply network without use of chemical disinfectants are as follows:

1. Presence of adequate concentration of disinfectant may reduce the risk of secondary microbial contamination, which can penetrate into the network through the failures, repairs or water backflow. It may affect re-growth of mainly coliform bacteria and colony counts [1]
2. Presence of disinfectant residue may indicate a system failure. If the network is monitored for concentration of the disinfectant residue, measurement of the reduced concentration of the disinfectant residue may be a signal for a contamination event that has occurred. [1]

Whether or not and to what an extent advantages or disadvantages of the disinfectant are reflected in drinking water depends mainly on the site of dosing and on the amount of the dispensed disinfectant. When considering use of a disinfectant, there is no simple answer to the question of whether the residual chlorine is necessary and beneficial for health and healthy quality of drinking water. [1] The answer naturally also depends on water quality entering the network, on hydraulic and building integrity of the network, and on the ability to apply good hygiene practices for the supplied drinking water. [1,12]

2.3 Experience of water management systems with supplies of drinking water without use of disinfectant

This work encompasses a detailed survey performed in total in nine different water management systems in the Czech Republic which are operated without use of the disinfectant. Most of them utilizes a UV lamp to ensure hygienic water supplies. Experience of transition and subsequent operation without any chemical disinfection is mostly positive. For example, the water management system of the city of Mladá Boleslav, supplying ca 60,000 inhabitants, has faced masking of the system integrity disruption. Discontinued chlorine dosing resulted in appearance of coliform bacteria in drinking water. Occurrence of the coliform bacteria was caused by failed horizontal seal of the storage chamber of one reservoir. [13]. The water supply network in Přelouč, supplying ca 19,000 inhabitants, experienced reduction of nitrites. When the chlorine-based disinfectant was used, increased nitrite concentrations occurred in drinking water. In case of full absence of chlorine, i.e. water was hygienically protected by a UV lamp only, nitrite concentrations decreased. [14] A smaller Vrbka municipal water supply network, supplying 77 inhabitants, faced the problem of increased iron content in the network before chlorination was discontinued. When sodium hypochlorite dosing was shut down and the UV lamp put into operation, iron concentrations were reduced to the standard values ($0.20 \text{ mg} \cdot l^{-1}$). [15]

It is possible to summarize that all examined water supply networks meet the microbiological requirements stipulated by the Decree No. 252/2004 Coll. The water treated without any chemical disinfectant is evaluated positively by the consumers, in particular its taste and smell, and there is no concern about disinfection by-products. In some systems the costs for drinking water production without chemical disinfectant are lower, and in some systems they are higher. It depends on technical condition of the system and its size. Obviously the technical condition of the water supply infrastructure affects the drinking water quality significantly. Thus the local conditions needs to be analysed first to estimate the potential water quality deterioration and also to determine the risk of such an event. [11, 16]

3 Initial assessment regarding transition to drinking water supplies without any disinfectant

By discontinuing chemical disinfection, the water supply system loses one of its security barriers. The other barriers must therefore be reliable and functional. It is important to assess whether or not the system is suitable for operation without any disinfectant. The assessment is particularly important for small water supply systems operated by a small operator or a municipality. It has to be considered what defects in water quality ("the undesired events") may occur when switching to supplies of drinking water free from any disinfectant, and what factors affect them. The effort is to cope with this process of transition so that possible disruptions in water quality may be avoided. Before the operator begins to consider water supply without any disinfectant, the water supply system should be subjected to the initial overall analysis of whether it is suitable for this type of operation at all. The water source, the water treatment plant (if included) and the distribution network with its structures should be reviewed. [5]

3.1 Water source

An underground source not affected by surface water is most suitable for operation without a disinfectant. Compared to surface water, the groundwater has an almost constant temperature throughout the year. Although the water temperature can change also during the distribution in the pipes [17, 18]. Groundwater does not need not be treated complexly, because the soil and the rocks above it fulfil the function of a filter and therefore in the majority of cases the water meets the microbiological and biological quality (according to the Decree No. 252/2004 Coll.) and the related overall biological stability. Coliform bacteria or E. coli present in groundwater, or a higher content of organic substances in water, indicate penetration of surface water or pollution that is usually of anthropogenic origin. It is important for non-disinfectant operation that the water source may contribute to the multi-barrier approach to protection of network operation and that its barrier may be effective. Proper barrier functions are achieved if, for example [5]:

1. Functional protective zone of degree I, which prevents unauthorized persons and animals from entering, is achieved by high-quality fencing, by secured access to the source (hood, etc.). Protective zone of degree II, where the requirements of § 30 of the Act No. 254/2001 Coll., on waters, (as amended), are observed, minimization of livestock grazing and farming round the source, etc.
2. Appropriate protection of the water source and its collection, well-made back-filling of the collecting devices, no turbidity events occur.
3. Sufficient depth of the collecting device guaranteeing that water quality may not be affected by surrounding soil loss by splash (surface water effect), confined groundwater level.
4. Good civil part condition, rodents, earthworms, insects, fallen leaves, etc. may not penetrate.

If the source meets these conditions, its functional barrier protecting it from contamination may be assumed. Functionality of the barrier should be confirmed by comparing with results of microbiological analyses performed during the last 2 to 3 years. If affection of the underground source by surface water (wash during rainfalls) is confirmed and the operator is interested in operation of the water supply network without chemical disinfection, replacement of chemical disinfection for UV radiation can be considered.

3.2 Water treatment plant (WTP)

If a water treatment plant (WTP) is the integral part of the water supply system, this plant should also have a functional barrier and contribute by its reliability to the multi-barrier protection of operation. A reliable barrier of the water treatment plant and its storage facilities is created by the following combination [5]:

1. Protection of WTP from penetration of unauthorized persons, game, rodents, insects, etc.,
2. Regular cleaning of all areas (disinfection of floors, removal of webs, etc),
3. Installation of doorsills to prevent dust, pollen, plaster and other impurities from entering the free level of the storage tanks filters, resulting in formation of biofilms and sediments in the storage facilities,
4. Water circulation, avoiding dead corners,
5. Regular cleaning and disinfection of storage tank walls, filters and their refilling,
6. Good technical condition of the storage tank, especially its sealing, preventing leakage of surface water in case of rainfalls,
7. Reliably working vent holes preventing mould formation, protection of these vent holes, especially in the storage and filter zone, from insects, pollen and dust,
8. Avoiding penetration of solar radiation into the filter and storage zones,
9. Filter washing should be determined, based on hydraulic losses on the filter,
10. Filtering should be done under simultaneous measurement of the water turbidity at the outlet,
11. Staff training, good hygienic habits of the staff (clean clothing and footwear to avoid bringing impurities from the outside), state of health of the staff in terms of infectivity, etc.

If the water treatment plant and storage facilities meet these conditions, a functional barrier protecting them against contamination can be assumed. Functionality of the barrier should be confirmed by comparing with the results of microbiological analyses performed during the last 2 to 3 years.

3.3 Distribution network

Distribution network with relevant structures, such as water reservoirs (WR) and pumping stations (PS) is another part of the multi-barrier protection approach. Reliable barrier of the distribution network and its structures is created [5]:

1. Adequate overpressure in the network (higher than 0.05 MPa) without any significant fluctuations,
2. Low failure rate of the network (less than 0.2 failures / km / year),
3. Low water loses,
4. Proper operation of the distribution system by the qualified staff,
5. Adequate pipeline speed ($> 0.5\ m \cdot s^{-1}$) preventing stagnation of water, formation of biofilm and development of microorganisms.

The same requirements, like for WTP with storage facilities, see above, are applied for the network structures such as WR and PS. According to the previous German field study, the internal distribution line of the consumer is the final place, where quality of transported water may be deteriorated [19]. If the aforementioned conditions are met, it can be assumed that the system is operated with the multi-barrier protection approach and is suitable for non-disinfectant operation, which fact should be confirmed by comparing with the results of microbiological analyzes of the last 2 to 3 years. A detailed description is contained in the German strategy for transition to water supplies without any disinfectant. [20]

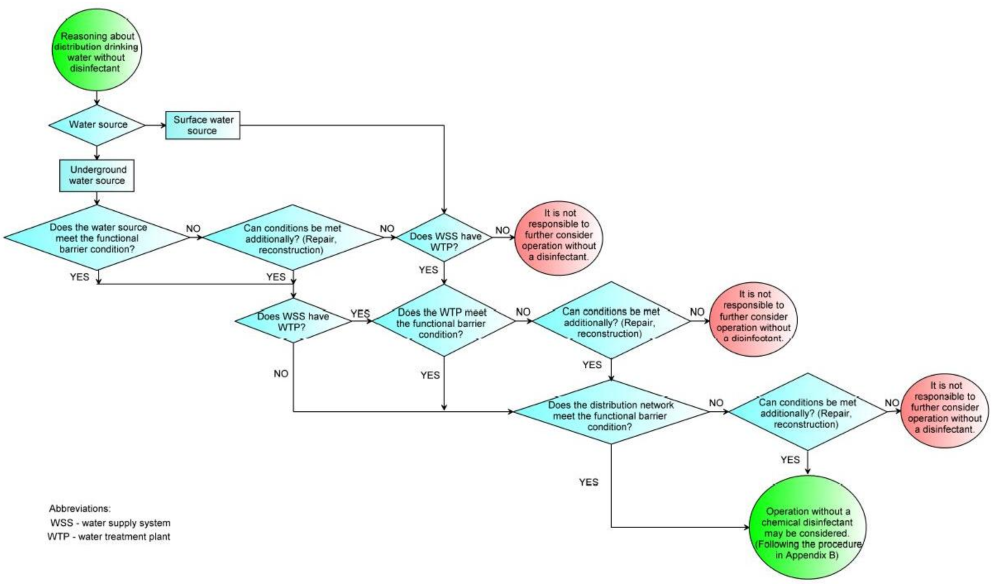

Fig. 1. Decision algorithm of first assessment for transition to supply of drinking water without disinfectant. [5a]

4 Process of transition to supply of drinking water without disinfectant

The decision algorithm of the first assessment is linked with the algorithm controlling the process of transition to the operation without use of any disinfectant, and the latter is extended by undesired events and factors that can occur immediately after discontinued chlorination. Under the undesired event (UE) [7] we shall understand the condition when the system (structure, system element, product) loses its desired feature or ability to perform the requested function. The undesired event is accompanied by occurrence of undesired consequences and is always defined for a particular element of the system. The undesired event is, in principle, a defect, i.e. water quality defect in this case. The general WaterRisk methodology and methodology of Water Safety Plans elaboration were used to describe (determine) UE and factors. [7] Three main undesired events that may occur have been defined for the process of transition to supplies of drinking water without use of any disinfectants, namely as follows:

1. UE 1 - Increased count of colonies at 22°C and 36°C,
2. UE 2 - Occurrence of coliform bacteria,
3. UE 3 - Occurrence of E. Coli bacteria.

4.1 UE 1-Increased count of colonies at 22°C and 36°C

The count of colonies is understood a group of the so-called heterotrophic (organotrophic) bacteria, needing a carbon source from organic substances for their growth. It is an indicator of microbiological recovery of drinking water. This indicator does not provide any direct evidence of pathogenic germs presence and its increased value in water is not connected directly with threats to human health. [21]

The factors that can affect the increased count of colonies are as follows [5]:

1. F 1.1 – Formation of biofilm
2. F 1.2 – Biological stability of water
3. F 1.3 – Water hold-up time in the network
4. F 1.4 – Presence of sediments at the bottom of the pipeline
5. F 1.5 – Concentration of free chlorine before discontinued dosing
6. F 1.6 – Water temperature

4.2 NS 2 – Occurrence of coliform bacteria

Total coliform bacteria are the bacteria commonly present in an environment, such as soil and vegetation. They are generally harmless. If presence of only the total coliform bacteria is detected, the natural environment is most likely their source. Faecal contamination is improbable in this case. However, if natural pollution could penetrate into the system, pathogens could appear here as well. It is therefore important to find and investigate the source of contamination.

The factors that may affect occurrence of coliform bacteria are as follows [5]:

1. F 2.1 – Impairment of physical and hydraulic integrity of the water supply system
2. F 2.1 – Water temperature

4.3 NS 3 – Occurrence of E. Coli

The E. coli indicator bacteria is a subset of coliform bacteria. In most cases it is completely harmless. However, there are also pathogenic strains (e.g. Escherichia coli O157: H7) [22] Presence of E. coli in drinking water is an indicator of fresh fecal contamination. E. coli is very sensitive to chlorine, even a very low concentration of residual chlorine can inactivate it. [8] The factor influencing occurrence of E. coli is as follows:

1. F 3.1 - Impairment of physical and hydraulic integrity of the water supply system.

5 Control algorithm of the process of transition to operation without use of a chemical disinfectant

The algorithm, controlling transition to supply without use of a chemical disinfectant, consists in assessment of water analyzes for the last 2 to 3 years. If microbiological abnormalities did not occur in the analyses in the past, a preliminary survey programme lasting for at least 2 months will be commenced. If microbiological abnormalities do not occur in the preliminary survey programme, dose of the disinfectant will be decreased gradually by ca 0.1 to 0.15 mg $\cdot$ l^{-1}. The surveillance programme then follows for 2 months as a minimum. Occurrence of water quality defects is monitored at this stage, see the undesired events shown above. If undesired events do not occur, dosage of the disinfectant can be discontinued completely. And again, it is necessary to perform the surveillance programme for at least 2 months. If neither any microbiological abnormalities nor undesired events occur at this stage, it can be stated that disinfectant dosing can be discontinued permanently. [5, 20]

The decision algorithm, controlling transition to supplies of drinking water without use of disinfectants, is based on the German strategy, stipulating 3 possible methods of system operation. The first method is drinking water supply in absolute absence of disinfection, both chemical and physical. This is possible only if a well-protected underground source is available. The assumption is that water enters into the distribution system complying with the microbiological and biological requirements stipulated by the Decree 252/2004 Coll., and the network does not provide suitable conditions for re-growth. The second option is to eliminate additional chlorination. This can only be realized if water after disinfection meets the microbiological requirements, and the network has such conditions regarding water flow rate, amount of sediments, concentration of biodegradable carbon, etc., that there is no need to maintain the disinfectant residue. The last option is to replace chemical disinfection for the UV disinfection. [20]. This solution is most frequently chosen in the Czech Republic.

6 CONCLUSION

The paper is focused on the possibility to operate drinking water distribution without application of any chemical disinfectant. Examples of the systems using chemical disinfectants neither for production nor for distribution of drinking water have been described and documented.

The fact that foreign chemicals of disinfectants, which - under some circumstances - may create toxic by-products of disinfection, are not brought into drinking water is the undisputed advantage of operation without a disinfectant. Reaction of chlorine can result in conversion of high-molecular natural organic compounds into simpler substances serving as a substrate for bacteria. No serious microbiological water quality defect has occurred in absence of a disinfectant in any of the systems that have discontinued chemical disinfection. Only a short-term increase in colony count due to biofilm re-formation was observed. Reduced iron concentration in the network, reduced nitrite content and positive evaluation of water smell and taste by the consumers is the positive experience of the water management system of this operation.

The paper also describes the process controlling transition to drinking water supply without a disinfectant, based on the German strategy. However, before the operator begins to consider switching to operation without use of chemical disinfection, initial assessment should be made, whether or not the water supply system in question is suitable for this type of operation. Individual problems that may arise at the water source, in the water treatment plant and the distribution network, which could prevent operation without use of a disinfectant, have been mentioned here. This may include, for example, insufficient water source protection, inadequate water treatment due to raw water quality, poor technical condition of the water treatment facility (unprotected air filtration, absence of thresholds under the storage chamber door, etc.), non-observance of hygiene standards by the operators, water leakage in combination with vacuum events, etc. The initial assessment procedure was displayed through the decision algorithm. The initial assessment is linked with the above-mentioned German strategy complemented by definition of possible undesired events and their factors which may occur immediately after discontinued chlorination. Three major undesired events have been defined: UE 1 - Increased count of colonies at 22°C and 36°C, UE 2 - Occurrence of coliform bacteria, and UE 3 - Occurrence of E. coli. Occurrence of coliform bacteria and E. Coli has been broken down into two undesired events, because the coliform bacteria are restricted by the Decree by the limit value only, i.e. be exceeding it, water loses the respective quality, but water supply is not interrupted, whereas if the limit value is exceeded in case of E. Coli, which is subject to the highest limit value, water supply must be interrupted unconditionally and an alternative drinking water supply source must be ensured.

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