

# UNDESIRABLE CONSEQUENCES OF INCREASED WATER TEMPERATURE IN DRINKING WATER DISTRIBUTION SYSTEM

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DOI: 10.17973/MMSJ.2019\_12\_2019158

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The article is focused on the description of problems that can be caused by increased temperature of drinking water in public drinking water distribution system (DWDS). Increased water temperature is an actual issue that the water industry has had to address in recent years, particularly as a result of the ongoing climate change. In recent years, long periods with high air temperatures have been more frequent than before. High air temperatures warm soil horizons and this results in an undesirable increase in drinking water temperature in water mains.

Temperature is a physical, sensible indicator of water quality that affects a variety of chemical, biological, and microbiological processes in water. Therefore, the optimum temperature range of 8–12 °C, which is to be achieved by the drinking water in the DWDS, is set by Decree of Ministry of Health of the Czech Republic no. 252/2004 Coll. Long-term high level of water temperature also contributes, among other things, to the development of the microbiological component of water in the DWDS and to the deterioration of organoleptic characteristic such as unpleasant odour or taste. The paper summarizes the technical regulations that are designed to provide the recommended water temperature in the DWDS, as well as the specific consequences and operating faults that may occur when water temperature is outside the optimum range of values. In view of the conclusions of available studies focused on predicting the future climate in the Czech Republic, it can be assumed that in the near future more frequent problems of operation can be expected in water supply systems due to unacceptable drinking water temperature. Above all, there will be water quality disturbances involving temporary deterioration of organoleptic, biological and microbiological indicators.

## KEYWORDS

drinking water; drinking water distribution system; water supply; water temperature; water quality; flushing

## 1 INTRODUCTION

The definition of drinking water is set by Public Health Protection Act No. 258/2000 Coll. Individual parameters of drinking water quality and their limits are set out in the related Decree No. 252/2004 Coll., which specify the hygiene requirements for drinking and hot water and the frequency and range of drinking water control. Ensuring the continuous supply

of drinking water in the required quantity and quality, which meets the requirements of Decree No. 252/2004 Coll., belongs to the priorities of drinking water supply managers. Drinking water outages or sudden water quality deterioration are perceived negatively by consumers and may severely complicate the functioning of the society in the short term [Piratla 2015]. In 2018, the Decree No. 70/2018 Coll., which updating the Decree No. 428/2001 Coll, was issued for the purpose of ensuring the safe operation of public drinking water supply systems. This Decree sets up the obligation for water utilities to develop a risk analysis. The main goals of this imposed obligation are to identify a hazard in the drinking water supply system, to define the failures that may arise and to quantify the risks generated by these failures. In the same time, the undesired consequences of these failures are to be assessed and, if the risks are unacceptable, corrective measures to reduce them should be proposed [Tuhovcak 2010].

Water quality during its distribution from source, respectively from water treatment plant, to the customers, among other things, is influenced by the pipe material and age, the attributes of the internal surfaces with which the water is in contact for a long time and the hydraulic conditions in the water supply network. The operator's effort is to prevent significant deterioration of water quality during its distribution through the DWDS. The goal of drinking water supply should be seen as providing good quality at the customer's tap rather than only at the point it leaves the water treatment plant [Liu 2017]. In connection with this, the assertion that the technical condition of the pipeline through which the water is distributed determines its quality at the point of consumption, because the quality of tap water can only be as good as the condition of the pipes it flows through [Rheingans 2006; Misko 2010; Ainsworth 2013]. Loss of hygienic safety of drinking water can also be caused by leaks and failures, where, for example the contaminant can enter the pipeline from the surrounding soil due to temporary loss of water pressure in the pipeline. The occurrence of pipe failures and bursts is influenced mainly by the load on the surface, the material and the age of the pipe, the diameter, the corrosion and the surrounding conditions, in particular by the temperature [Rezaie 2015; Boxall 2006; Speta 2014].

The surrounding area plays an important role in changing the water temperature in the DWDS. Sufficient soil layer over the pipe not only provides protection from mechanical loads from the surface, but also from the climatic effects. It serves as a protection against frost that causes pipeline bursts and excessive heating, which undesirably heats the drinking water in the pipe [Speta 2014].

The issue of increasing the temperature of water in the public DWDS is particularly important for water supply systems that are operated without the use of a disinfectant, which creates a disinfectant residue. Disinfectant residues include oxidants such as ozone and chlorine compounds. Ozone is a more efficient oxidant than chlorine, which is most commonly used [Jeligova 2010]. The presence of a disinfectant at an appropriate concentration may prevent secondary microbiological contamination and prevent further growth of coliforms and colony units [Kooij 2014]. When moving the water supply system to a non-disinfectant operating mode, it is necessary to perform a long-term monitoring of the water quality and to verify that the water supply is suitable for this type of operation [Rajnochova 2018]. Given the ongoing climate change and the climate model predictions, it can be assumed that the increased drinking water temperatures in public water supply networks will occur more frequently, especially during the summer months. The water temperature is affected by the

climatic conditions of the environment. Climate change simulation models for Central Europe predict an increase in average temperature, more frequent occurrence of hot summer and tropical days, and a change in rainfall system [CHMI 2019].

Obviously, due to global climate change, a gradual elevation in the problems arising from the increased temperature of drinking water in the water distribution network can be expected. A very likely scenario will be a temporary drinking water quality deterioration in the DWDS and a higher probability of exceeding the limits of microbiological parameters of drinking water during the summer season. The occurrence of increased water temperatures has already been confirmed by a survey among water distribution network operators in the Czech Republic. The water temperature rise can already occur in the water source or during the distribution in the DWDS.

Due to its location, the Czech Republic relies entirely on hydrometeorological rainfall, which is the only renewable source of water. Rainfalls complement the capacity of surface and underground water sources. In 2017, approximately 40 % of the population in the Czech Republic were supplied with drinking water produced from underground sources, approximately 39 % of the population were supplied with drinking water from surface sources and approximately 21 % of the population were supplied with drinking water produced from mixed sources, which are a mixture of surface water and groundwater [NIPH 2018].

Acceptable quality of raw water and sufficient capacity of a water source is a prerequisite for a reliable drinking water supply system. The Czech Republic has been dealing with drought problem for a long time. Drought affecting not only the quantity but also the quality of raw water in water resources. Meteorological causes of drought are a combination of the occurrence of long periods of over average air temperatures, a period of under average rainfall and considerable evaporation. Between 2014 and 2017, a total rainfall deficit of approximately 250 to 300 mm was recorded in the Czech Republic, which is 44 % of the average rainfall in 2017 [MA 2017]. This is a very significant water sources deficit. In addition, there is an uneven distribution of precipitation in space and time, which has a negative impact on water source replenishment [Danhelka 2019].

### **1.1 Underground sources**

The irregularity of precipitation lasting several years results in insufficient replenishment of shallow and deep underground water sources. According to the results of the Czech Hydrometeorological Institute (CHMI) observations, in 2018 the drought was the worst in terms of water levels of shallow wells, springs and deep wells [Danhelka 2019]. The advantage of underground sources is generally a greater stability of quality and temperature of raw water [Pitter 2015].

### **1.2 Surface sources**

Surface sources are influenced by climate change not only in terms of insufficient replenishment of their capacity, but also in terms of raw water quality deterioration [Danhelka 2019]. Reduced volumes in reservoirs and rivers contribute to the acceleration of water heating, as well as increased evaporation from water surface. Increased water temperature contributes significantly to the development of microbial component contained in water [Pitter 2015]. Deteriorated raw water quality can result in imperfect removal of pollution if the treatment process does not adapt to conditions, and then treated drinking water enters the distribution system from the water treatment plant may contain physical loads (particles),

microbial loads (cells) and nutrient loads (organic and inorganic nutrients), respectively, water may exhibit essential organoleptic defects that arise from the action of microorganisms in warm water that have not been removed at the water treatment plant [Liu 2013; Prest 2016].

## **2 PROBLEMS CAUSED BY INCREASED WATER TEMPERATURE**

The temperature as well as colour, turbidity, odour and taste, is an organoleptic indicator of the quality of drinking water that are detected by the sensory organs [Pitter 2015]. Since 2014, the temperature is determined at each sampling of drinking water according to the requirements of Decree No. 252/2004 Coll. in its current version, which sets its recommended value by an interval of 8-12 °C. The high water temperature alone does not cause a loss of hygienic water safety, but in combination with other factors it can create suitable conditions for problems and risks. Decree No. 252/2004 Coll. implements the requirements of the European Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. However, this European regulation does not contain any limit or recommended range of drinking water temperature values.

### **2.1 Organoleptic properties of drinking water**

Water warmer than 15 °C is not as refreshing as cooler water. Water colder than 5 °C can cause medical issues with gastrointestinal tract to more sensitive consumers [Pitter 2015]. According to conducted studies, drinks cooled to 0 °C to 10 °C consumed during and after sports activities give consumers a greater sense of pleasure, reduce thirst more efficiently and taste of cooler drinks is considered better than those of drinks with higher temperature. These studies were conducted with drinks with temperature up to 46 °C [Burdon 2012]. The temperature of the consumed water also influences the perception of the taste of the food. Drinking water cooled to 0 °C suppresses the sweet taste of the food. The sweetness is not so intense. Hot water (heated to 50 °C) or water at room temperature (specifically 20 °C) causes a more intense sweet taste of the food. The effect of water temperature on salinity and bitterness has not been demonstrated [Mony 2013].

The unpleasant odour of water is caused by the presence of odorants that produce a specific odour. Odour intensity is a function of aqueous concentration and water temperature. Increased water temperature causes higher odour intensity. Microbial by-products, disinfectants, and disinfection by-products are common drinking water odorants. The resulting odour depends on the type of substance contained in the water. Geosmin, MIV, tran-2 and cis-nonadienal are compounds that are metabolites excreted by actinomycetes, cyanobacteria, or algae and are very difficult to remove by conventional water treatment processes. Another most common compounds creating unpleasant water odour are free chlorine and isobutanol. Isobutanol has been identified as a by-product from ozonation and chlorination. All of above compounds have a specific odour threshold concentration and create a specific odour: geosmin (earthy, beet-like), MIB (musty, earthy), nonadienal (cucumber, grassy), n-hexanal (lettuce heart, grassy), isobutanol (malty, sweet, fruity) and chlorine creates a typical chlorine odour. Chlorine odour has the unique ability to mask earthy and musty odours present, and this is one of the reasons why earthy and musty odours are better detected when chlorine levels are lower. The chlorine odour is one of the most common drinking water complaints [Whelton, 2001].

## **2.2 Influence of temperature on course of chemical and biochemical reactions**

The rate of chemical and biochemical reactions in water is higher at higher temperatures [Pitter 2015]. The biological processes in the distribution network are influenced by temperature, also by the age of the water and the stagnation, the hydraulic parameters (flow velocity and pressure conditions), the pipe material and the presence of the residual chlorine disinfectant [Prest 2016]. For example, when using a chlorine disinfectant, nitrates can convert into nitrites at elevated temperature. Consequently, nitrates in high concentrations can cause methemoglobinemia [Hampel 2010].

## **2.3 Physical characteristics of water depending on its temperature**

The temperature also influences the solubility of the substances in water. With increasing temperature, the solubility of the substances increases in most cases and the solubility of the gases decreases with increasing temperature. With increasing water temperature, the density and viscosity of the water decreases. When the water temperature rises from 10 °C to 20 °C, the viscosity drops by 30 % [Pitter 2015].

## **2.4 Influence of temperature on chlorine decay**

Increased water temperature is one of the factors that accelerate the process of chlorine consumption and decay in water [Pitter 2015, Rucka 2017]. It also affects the rate of disinfection by-products creation that are potentially harmful to health. These include, for example, carcinogenic trihalomethanes (THM) or phenols, which cause unpleasant chlorine odour in consumers [Kooij 2014, Blokker 2013].

## **2.5 Growth of microorganisms**

Increased temperature improves microorganism growth conditions [WHO 2011]. Higher water temperatures (above 25 °C and more) create more propitious conditions for the growth and development of microorganisms that are contained in the biofilm [Sasek 2009]. In all parts of the water supply system, the properties of the microbiological component are affected, or the surrounding in which it is located and where it can grow and reproduce. In order to ensure the biological stability of the drinking water, it is important to ensure sufficient water treatment. Treated water should not promote further bacterial growth by its composition, nutrient content and bacterial community. It is necessary to ensure conditions that will not support undesirable changes in the microbiological composition of the water during distribution in the DWDS and domestic drinking water distribution system [Prest 2016].

Infectious diseases caused by pathogenic bacteria, viruses and parasites are the most common and widespread health risks associated with the distribution of drinking water. Contamination may occur if the safety of any part of the drinking water supply system (source, treatment plant, distribution network) fails. Microbiological water quality may vary rapidly and widely. Short-term peaks in pathogen concentration may increase the risk of disease and may also trigger outbreaks of waterborne diseases. Microorganisms can accumulate in sediments and mobilize when flow increases significantly [WHO 2011].

Waterborne pathogens, such as Legionella, may grow and multiply in water, whereas other host-dependent waterborne pathogens, such as noroviruses and Cryptosporidium, cannot grow in water, but are able to persist [WHO 2011].

Host-dependent water pathogens gradually lose viability and the ability to infect, after leaving the host's body. The rate of

decay is usually exponential, and the pathogen will become undetectable after a certain time. Low persistence pathogens need to quickly find new hosts and are more likely to spread by person-to-person contact than by drinking water. The temperature of the water significantly influences the persistence of pathogens. Decay is usually faster at higher water temperatures and can be mediated by the fatal effects of ultraviolet (UV) radiation in sunlight acting near the water surface [WHO 2011].

The combination of a relatively high amount of biodegradable organic carbon, low residual chlorine concentration and increased water temperature can allow the growth of Legionella, Vibrio cholerae, Naegleria fowleri, Acanthamoeba and nuisance organisms in surface sources and during water distribution [WHO 2011].

## **2.6 Biofilm**

Increased water temperature promotes the formation and development of biofilm on the piping walls and other water structures such as accumulation tanks. A biofilm is essentially a diverse formation of cell clusters that are encapsulated by matrix. Between these enveloped clusters there are empty spaces (channels) that allow water to flow. Nutrients, oxygen are transported by water through the channels to the microcolonies and also the waste products of their metabolism are removed by these channels. The live and fully hydrated biofilm is composed of about 15% of its volume by cells and about 85% of the volume is formed by the matrix, which is a product of cell clusters and may further contain other inorganic particles, such as mineral crystals, corrosion particles, clay particles clay and sand and sludge, depending on the surrounding in which the biofilm were formed in. The biofilm matrix creates cell protection against disinfectants. It prevents the transport of disinfectants to the biofilm or binds the disinfectant directly due to chemical reaction with them. The pipe material affects the biofilm growth. The various materials allow, to a lesser or greater extent, the formation of a biofilm at the interface between the pipe wall and the distributed water. For the biofilm stability, the flow rate of the water in the pipeline is important. Increasing the flow speed often results in the release of the biofilm layer from the pipe walls [Sasek 2009, Rucka 2014].

## **3 RESULTS OF THE QUESTIONNAIRE SURVEY BETWEEN SELECTED PUBLIC WATER MANAGEMENT OPERATORS IN THE CZECH REPUBLIC ON THE PROBLEM OF INCREASED WATER TEMPERATURES IN THE DISTRIBUTION SYSTEMS**

The state of solution of the issue of unsatisfactory water temperature in the drinking water distribution systems in the Czech Republic was mapped by the authors of this article in the form of a questionnaire survey. The questionnaire was sent to a total of 24 water companies respectively to their separate operating divisions.

The aim was to get an overview of the attitudes of the water operators across the Czech Republic, so that the results obtained were as general as possible and characterize the state throughout the country. Of the total number of 24 sent operators, 16 replied. These companies operate water distribution systems with total length from 500 to 5.000 km with varying diameters and materials (metals, plastic and cement pipes).

The questionnaire focused on the following topics:

### **3.1 Occurrence of water temperature above recommended values according to Decree No. 252/2004 Coll.**

In response to this question, 15 out of 16 respondents confirmed that the recommended interval of drinking water temperature values of 8–12 °C is regularly exceeded during the summer (June to September). Samples were taken from the distribution network from the hydrants, from the sampling valves in the water meter shafts or from the taps at the consumer. Sampling is based on the methodology given in the ČSN ISO 5667-5. For sampling at the consumer, the outlet fitting which is the first behind the water meter in the domestic drinking water distribution system is selected primarily. The aim is to eliminate the influence of the internal drinking water distribution system on the analysis result. However, it is not always possible to adhere to the provisions of the technical regulations and it cannot be completely ruled out that the quality of the water collected at the tap does not exactly correspond to the quality of the water in the public water supply.

### **3.2 Method, frequency and location of water temperature measurement in drinking water supply network**

The temperature measurement is in accordance with the requirements for sampling and methods of drinking water analysis specified in Decree No. 252/2004 Coll. The water temperature is determined at each sampling because it is part of a reduced analysis. The obligatory frequency of drinking water analysis stated in Decree No. 252/2004 Coll. forms the lower limit of the total number of performed analysis. The total amount of performed drinking water analysis is individual and depends on the judgment and possibilities of each operator.

### **3.3 Occurrence of problems caused by increased water temperature (e.g. development of growth of coliforms, occurrence of *Legionella pn.* and other microbiological indicators)**

A total of 9 respondents rejected the possibility that on their operated distribution systems there were problems in the past for which the increased temperature of the drinking water could be considered.

A total of 6 operators admitted that over-the-limit values of microbiological and biological indicators would occasionally occur in their distribution systems. These were mainly indicators: colony count at 22 °C and colony count at 36 °C. In addition, 3 of them admitted that coliforms were also present.

Exceeding the limit values of these microbiological indicators is, in the opinion of 3 operators, the result of a combination of several factors:

- increased water temperature in the distribution network (a longer period with over average air temperatures affects the water temperature increase),
- water age (mainly in the dead ends where there is little consumption),
- low doses of disinfectant and low level of residual disinfectant.

These conclusions fully coincide with previously conducted water quality researches in drinking water distribution systems [Rajnochova 2018].

One operator admitted that microbiological problems do not occur in the distribution network but rather in the raw water source.

### **3.4 Consumer complaints about water temperature or health problems that may have been caused by increased water temperature**

Complaints about unsatisfactory water temperature were reported by only one of the surveyed operators. This complaint occurred during the summer. However, the legitimacy of this complaint is uncertain because, in the respondent's opinion, the temperature of the tap water could have been influenced by the long residence time and the flow rate of the domestic drinking water supply system. Internal water distribution systems are not in the competence of the water main operator. Complaints about health problems caused by increased water temperature were not reported by any of the respondents. According to them, the most common reasons for customer complaints are the decreased organoleptic properties of water, such as turbidity, colour and chlorine odour.

### **3.5 Occurrence of increased water temperature in water sources during summer season**

There are no significant problems with increased water temperature in underground sources. Groundwater temperature is generally more stable and is not significantly influenced by climatic conditions. According to respondents' answers, 20 °C was not exceeded for underground water sources. The temperature in these sources is constant in lower values depending on the depth of the borehole. Respondents using underground resources also did not experience significant fluctuations in water temperature.

Some surface sources have exceeded 20 °C during the summer months, but not the 25 °C limit. These higher water temperatures in the sources were due to the long-term elevated air temperature, lowering the water level in the reservoir, resulting in faster and more intense water heating in the reservoir.

### **3.6 Solution of occurrence of increased water temperature in drinking water distribution systems**

If the reservoirs are the source of raw water, this problem is resolved by changing the raw water consumption horizon. If the surface source is a river, elevated temperatures are not solved.

In many places, water from the underground and surface sources is mixed all year round. However, this is due to improvements in other raw water quality indicators (usually hardness) than temperature.

### **3.7 Reactions of Public Health Protection Authority**

A similar questionnaire was also contacted by the relevant regional office of the Public Health Protection Authority, for which the Ministry of Health of the Czech Republic responded collectively. The Public Health Authority's attitude to the issue of increased water temperature in the distribution network is reserved. Water temperature is not considered an important indicator of drinking water quality, which could cause loss of sanitary safety of drinking water.

## **4 POSSIBILITIES OF PREVENTION INCREASING WATER TEMPERATURE IN THE DRINKING WATER DISTRIBUTION SYSTEM**

In order to solve the above-mentioned problems, methods that are not costly can be considered. The aim of operators is to supply consumers with high quality drinking water at the lowest possible price. Indeed, increasing the price of water, whatever the reason, causes consumer discontent.

Water temperature indicator was included in Czech legislation in 2014 by Decree No. 83/2014 Coll. amending Decree No. 252/2004 Coll. Until 2014, the determination of water temperature during sampling of drinking water was not mandatory.

#### 4.1 Compliance with technical regulations in the design and construction of the distribution network

This is essentially a preventive step. Czech technical standards set out in detail the requirements for implementation and technical design of water pipes and internal water pipes. Relevant regulations are:

ČSN 73 6005 Spatial arrangement of networks of technical equipment valid since October 1994. This Czech Standard specifies principles for the arrangement of networks stored in open areas and in the area of roads in urban areas and undeveloped areas. In terms of water temperatures, the essential part regulating the mutual distances of utilities during parallelism and crossing. Especially the distance between the drinking water pipes and hot water or steam networks. Insufficient mutual distance could result in local heating (in the case of crossing) or continuous heating (in the case of longitudinal paralleling) of the drinking water. The minimum crossing distance is 0.2 m and 1.0 m when the bearing is parallel.

ČSN 75 5401 Design of water pipes valid since January 2008. This standard specifies the smallest recommended soil cover layer height of water pipes in open area, depending on the type of soil and diameter of the pipe (see Tab. 1).

TYPE OF SOIL	DN ≤400	DN >400
LOAM	1.2 m	1.0 m
LOAMY SAND	1.3 m	1.1 m
SANDY	1.4 m	1.2 m
GRAY AND SCALE	1.5 m	1.3 m

Table 1. Minimum pipe cover height depending on soil type and pipe diameter according to ČSN 75 5401

In the case of appropriate conditions for which, according to this standard, a higher water temperature and suitable climatic conditions are considered, or if appropriate technical measures are proposed, the pipe cover height may be reduced. However, its reduction must be assessed in terms of static reliability and the effect of climatic conditions. At the same time, the cover height should not be more than 1.0 m above the recommended minimum cover (ie maximum 2.5 m and in the undeveloped area the maximum coverage height is up to 2.6 m according to ČSN 73 6005). This is due to the easier localization of pipeline failures and bursts and the cost reducing during the construction of the water supply.

EN 806-1 to EN 806-5 Water installations inside buildings intended for human consumption valid since 2002. This European Standard specifies requirements and provides recommendations for the design, installation, modification, testing, maintenance and operation of internal drinking water mains. It has a total of five valid parts

From the point of view of water temperature in domestic drinking water distribution systems, ČSN EN 806-2 focused on design and ČSN EN 806-5 focused on operation and maintenance are essential. EN 806-2 contains, among other things, the principles for protecting the internal water supply system against external area temperatures, both against freezing of pipes and undesirable heat gains. „Cold drinking water pipes must be adequately protected against heat gains by either placing them away from heat sources or by isolation.

*The requirements for isolation against heat gains are identical to those for heat loss isolation.“*

The thermal isolation requirements are as follows:

- Minimum thickness designed according to local or national requirements,
- The isolation material must be resistant or protected by a suitable cover against mechanical damage, humidity and rain, groundwater, pests.

CSN EN 806-5 specifies requirements and provides recommendations for the operation and maintenance of internal drinking water supply systems. It contains procedures that need to be carried out, for example, in the development of failures, water quality changes and other undesirable situations. The standard draws attention to the increased risk of bacterial growth, such as Legionella, in case of stagnation or unsatisfactory water temperature.

#### 4.2 Increasing water flow - controlled flushing of pipelines

The end parts of the water supply system, from which there is not enough consumption, household connections (often to weekend dwellings) and oversized hydraulic circuits are significantly endangered by the risk of water temperature increase. These parts of the system are at risk of water stagnation, water aging, which in combination with low consumption and overheating can lead to a significant deterioration of microbiological indicators [Rajnochova 2018]. The preventive measures are an optimized design of pipelines that will ensure sufficient flow velocities or regular and controlled flushing of these parts to ensure regular water volume change. Fine sediments accumulated at the bottom of the pipe will be flushed out of the pipes by controlled flushing of the pipeline. These sediments protect the microorganisms in the water from the effects of disinfectants [Kooij, 2014]. The aim of the controlled pipe flushing is to safely and completely rinse the sediment from the water pipes with minimal negative impact on the comfort of water consumers. During flushing, it is always important to keep the hydraulic behaviour of the distribution network under control and use only the necessary amount of water for it. Flushing the water network involves a number of risks: (1) pressure loss, (2) loss of control of the water quality in the DWDS and the occurrence of an uncontrolled turbidity event, (3) incomplete flushing of sediment from the pipeline, (5) the entry of turbid water into the household connections [Rajnochova 2019].

#### 4.3 Mixing water from two different sources or replacement the water source

Assuming suitable water chemistry, one of the possibilities of water temperature optimization is mixing of water from various water sources (underground and surface). In the summer months, surface water resources are generally more susceptible to temperature rise to 20 ° C and above, and underground water resources are more temperature stable and the water in them is cooler. Groundwater is significantly less affected by air temperature. Mixing of raw water from two or more sources already occurs in several water systems. According to available information, 21% of the Czech Republic's consumption is supplied with mixed water. However, the water is not mixed because of the unsatisfactory water temperature, but to improve the water quality indicators, especially the hardness, i.e. the concentration of magnesium and calcium. Or the secondary surface (or underground) source serves to replenish the capacity of a less abundant underground (or surface) source. The mixing ratio depends on the yield of the sources.

#### 4.4 Accuracy of temperature measurement during sampling

To make the sampling results (the mandatory part of which is temperature measurement) relevant, the legal regulations (Decree No. 252/2004 Coll.) stipulate that the Czech technical standards must be complied with during sampling. In terms of temperature measurement, the relevant standard is ISO 5667-5 Water Quality - Sampling. This ISO standard specifies the principles of proper sampling of drinking water from water mains and water treatment plants. What is essential is a passage that describes the process of cleaning, disinfecting, and rinsing the household connection pipe before sampling.

Cleaning, disinfecting and flushing the pipes before taking water samples depends on the purpose of sampling. If the water quality supplied to the consumer by the public distribution system is controlled, flushing and cleaning of the sampling points are done. When taking samples from water tanks, the water is allowed to drain freely for 2 to 3 minutes to remove the stagnant water from the sampling line. If the above interval is not enough, the volume of water that needs to be replaced in the pipeline is calculated and the required time and speed are estimated. The actual flushing time is five times the estimated flushing time.

When tap water sampling is performed, the procedure is similar to sampling water from water tanks. If this is not a microbiological sampling, before tapping, taps are cleaned and then flushed. Stagnant water is allowed to flow from the tap for 2 to 3 minutes at a constant flow rate. The flushing is terminated only after the effluent temperature has stabilized. The flushing time may take up to 30 minutes, for example, when sampling from the blind branches of the main pipe branch where sediment may be deposited, which must be flushed before sampling. During sampling the water flow rate should be constant.

## 5 CONCLUSIONS

The paper provides a basic overview of drinking water temperature, which is supplied by public DWDS in the Czech Republic, including a comprehensive overview of legislative conditions. In the past, the authors of the article conducted their own extensive questionnaire survey among several larger water utilities in order to map their practical experience, problems and attitudes to the issue of increased drinking water temperatures in the DWDS. At the same time, the position of Public Health Protection Authorities on this issue was also identified. From the reactions of operators and the Ministry of Health of the Czech Republic, it can be concluded that water temperature is not considered as a primarily important indicator of drinking water quality. In the subconscious of the professional public, the most important indicators are those with the limit of the highest limit (for example, microbiological indicators), when they are exceeded, the water loses hygienic safety.

However, according to recently conducted research and studies, the increased temperature of distributed drinking water creates the potential for the activity of these microorganisms, which leads, among other things, to deteriorate the organoleptic properties of drinking water.

Since 2014, the temperature of water is a mandatory part of every drinking water sampling. The survey conducted among operators, also according to publicly available data and according to the official reports of the National Institute of Public Health, regularly exceeds the recommended values of water temperature 8–12 °C during the summer season. However, the surveyed water operators did not confirm that

the water temperature in their DWDSs exceeded 25 °C. The National Institute of Public Health, which collects results on all water sampling performed throughout the Czech Republic, has published information that in 2015 the maximum water temperature was 27.6 °C in public water supply system, 33.0 °C in 2016 and 28.9 °C in 2017.

The water temperature may be affected throughout the whole distribution system. In the raw water source at the input to the system, the water has an initial temperature that practically cannot be influenced by the water operator. The water temperature in the source, unlike the water in the distribution network, is not equipped with any limit, which, if necessary, would serve as an indicator for shutting down the source. Only the Decree No. 428/2004 Coll., which sets assessment requirements for drinking water sources for inclusion in the categories of treatability, is considered. As mentioned above, underground water sources are more suitable in terms of water temperature and are not so much influenced by the climate of the surrounding area and are more stable all year round in terms of water quality. In accumulation in water tanks, the water temperature can be reduced or increased, depending on the type of the water tank, its technical condition and thermal isolation. Tower water tanks are more susceptible to warming up the water in the summer months, and the water temperatures will be more likely to cool in ground water tanks. Sufficient depth of pipe laying, respectively sufficient soil cover height, should ensure the pipes protection against the external influences and the heating or freezing. Compliance with technical regulations and minimum mutual distances between two utility networks (for example, drinking and hot water pipes or steam pipe) should prevent the heating of water in the DWDS. Significantly, the dead ends, where the consumption is low, and household connections are at risk of increasing the water temperature. Failure to comply with technical standards, insufficient thermal isolation, crossings of domestic drinking and hot water installations may result in increased water temperature in the domestic drinking water supply systems.

Despite the fact that the water temperature in some places significantly exceeds the values recommended by Decree No. 252/2004 Coll., this water quality indicator is not perceived by the professional public with considerable respect. Despite the opinion that the Ministry of Health has on water temperature, the influence of increased water temperature on the development of microbiological recovery is proven by several studies [Rajnochova 2018, Kooij 2014]. Exceeding the microbiological water quality limit values, operators take corrective action, such as: increasing the dose of residual disinfectant, secondary chlorination in the distribution system, flushing of troublesome pipelines or, in extreme cases, Public Health Protection Authorities prohibiting the use of water from public water supply for drinking purposes.

## ACKNOWLEDGMENTS

This paper was financially supported by the research project of the Brno University of Technology reg. no: FAST-J-19-6066.

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