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Selected causes of exploitation problems caused by secondary contamination of drinking tap water

Wybrane przyczyny problemów eksploatacyjnych wywołanych wtórnym zanieczyszczeniem wody wodociągowej

Abstract

The paper presents selected causes of problems related to the widely understood phenomenon of secondary contamination of drinking tap water caused by corrosion. The legal aspects, related to the formal responsibility for water quality in water supply systems: cold water and hot water, according to the way it is prepared, have been analysed. The main causes of the deterioration of water quality in water supply systems were characterized by the criteria for assessment of the corrosivity and aggressiveness of the water. Proposals for actions which should be undertaken to prevent secondary water contamination in water supply systems have been drawn up.

Keywords: drinking tap water, secondary contamination of water, aggressiveness

Streszczenie

W pracy zaprezentowano wybrane przyczyny problemów związanych z szeroko pojętym zjawiskiem wystąpienia wtórnego zanieczyszczenia wody wodociągowej, spowodowanego korozją. Przeanalizowano aspekty prawne związane z formalną odpowiedzialnością za jakość wody w instalacjach wodociągowych: wody zimnej i ciepłej wody użytkowej, w zależności od sposobu jej przygotowania. Scharakteryzowano główne przyczyny wystąpienia zjawiska pogorszenia jakości wody w instalacjach wodociągowych podając kryteria oceny korozyjności i agresywności wody. Opracowano propozycje działań, jakie należy podjąć w celu zapobiegania zjawiska wystąpienia wtórnego zanieczyszczenia wody w instalacjach wodociągowych.

Słowa kluczowe: woda wodociągowa, wtórne zanieczyszczenie wody, agresywność

1. Introduction

Modern technologies of water treatment allow water with better and better parameters to be introduced to water supply networks. However, this does not guarantee that consumers will receive water with equally good parameters. The direct effects of secondary contamination of tap water are suffered mainly by its consumers [4] but operational problems are also felt by water supply companies and, in the case of using district heating to prepare hot tap water, by heat-generating plants as well. In normal operational conditions, secondary contamination of water resulting from the supposed contact of tap water with the heating medium (heating water) is excluded due to the water heating in heating substations using a diaphragm. Heated water – hot tap water has no direct contact with heating water. Yet, problems appear connected with the occurrence of "red water" in cold and hot tap water systems. The main cause of this situation may be the technical condition and the configuration of the infrastructure responsible for supplying water to consumers as well as the lack of water treatment process stability [5]. The operating conditions of both the water supply network [3] and domestic distribution systems may also have an influence on water contamination. The highest risk is where water consumption is low. Additionally, the diameter of pipes and, above all, the ratio of the internal size of pipe surfaces to the amount of flowing water affect the content of metal ions and corrosion products. Secondary microbiological contamination of tap water connected with corrosion processes is possible. The presence of corrosion products on internal surfaces of pipes through which drinking water flows contributes to the creation of biofilm [5]. The intensity of the creation of this biofilm and its susceptibility to disinfection processes depend largely on the material of the system.

Tap water that stands for a long time in network and system tanks and pipes contributes to its contamination. Secondary microbiological contamination of water occurs when deposits come off the sanitary system walls. Biofilms created on surfaces of hot tap water domestic system pipes favour the development of *Legionella* bacteria. Disinfection of the network prevents secondary microbiological contamination [1, 15] but intensifies the corrosion process.

Water supply networks and domestic distribution systems are made mainly of materials which are prone to corrosion and deposit accretion. Such phenomena result in water quality deterioration [5] to the highest degree. Science has studied the corrosion of cast iron and steel in water supply networks for more than 80 years and in spite of the fact that this long period has allowed the problem to be described thoroughly, almost all scientists admit that corrosion of materials based on iron (steel, cast iron) is a very complex phenomenon.

Interactions between components of transported water and corrosion products present on pipework walls significantly change the quality of water mainly in a way that is undesirable to its consumers. Reactions taking place in corrosion deposits contribute to water quality deterioration in pipework, above all, as a result of the release of iron compounds, migration of elements from corroding materials and creation of compounds which have an undesirable smell. A straight majority of consumers' complaints to water suppliers is directed in connection with the occurrence of so-called "red" water in hot tap water domestic systems. This phenomenon is caused by the release of Fe(II) ions from cast iron and steel pipes which are then oxidized with oxygen dissolved in the water or remaining disinfectants, creating coloured floccules $Fe(OH)_3$. The occurrence of "red water" is strictly correlated with the cloudiness of water so the increase of this parameter will indicate the development of corrosion in the network. Most frequently "red water" appears at the end of networks. Legal regulations concerning water quality in domestic distribution systems and water supply networks as well as the operation of water supply and heat-generating networks are contained in relevant legislation.

2. Legal aspects of water supply to consumers

Pursuant to Article 3 (2) of the Crisis Management Act of 26 April 2017 [13] (JL no 89(590) as amended), the water supply system belongs to the critical infrastructure of the state and is ensured by the efficient operation of all its bodies.

Water supply and sewage treatment companies operate under the Act of 7 June 2001 on Collective Supply of Water and Collective Sewage Treatment as amended [14] (JL no 139 of 2015). Pursuant to Article 5(1) of that Act: "A water supply and sewage treatment company is obliged to ensure the ability of water supply and sewage devices possessed by such a company to supply the required amount of water under an adequate pressure and to supply water and treat sewage in a continuous and reliable manner, and to ensure that the supplied water and treated sewage are of proper quality".

The priority for water supply and sewage treatment companies should always be the quality of supplied water. Pursuant to §3(1) of the Regulation of the Minister of Health of 13 November 2015 on the Quality of Water Intended for Human Consumption [11] (JL no 1989 of 2015): "Water is safe for human health if it is free from pathogenic micro-organisms and parasites to the degree which constitutes a potential risk for human health, any substances in concentrations which constitute a potential risk for human health, does not display aggressive corrosion characteristics and meets:

1) basic microbiological requirements described in Annex no 1 to the Regulation;
2) basic chemical requirements described in Annex no 2 to the Regulation".

Water supply to consumers is affected by numerous conditions connected with the organizational and legal structure of water supply whose demonstration is presented in Fig. 1.

The Regulation of the Ministry of Infrastructure of 12 April 2002 on Technical Conditions Buildings and their Location Should Meet [9] also notices the necessity to secure the quality of tap water, i.e. to secure water against secondary contamination. According to § 113 of that Regulation "Products used for a domestic water distribution system should be selected taking into account water corrosivity so that its quality and the durability of the system would not be impaired and such effects would not be brought about by interaction of materials of which such products are made. A domestic water distribution system should be equipped with devices protecting against secondary contamination of water according to requirements concerning reverse flow described in the Polish Standard concerning protection against reverse flow".

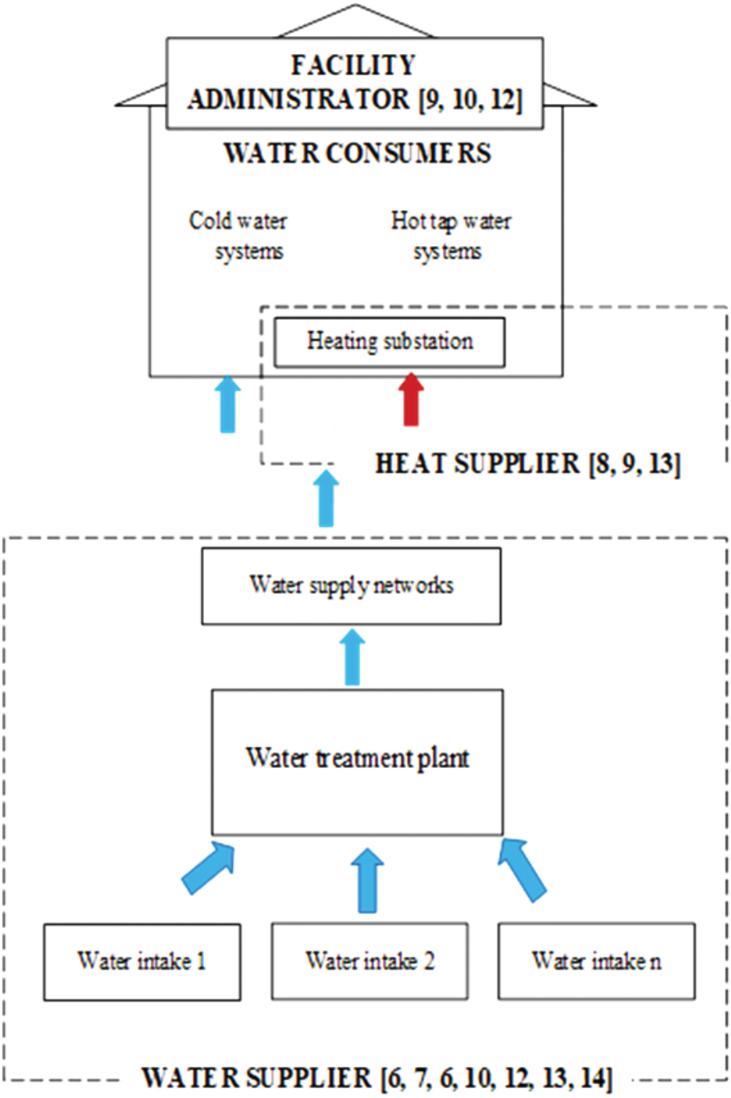

Fig. 1. Demonstration organizational and legal structure of water supply (own elaboration)

According to standard PN-EN 1717:2003 [7] indicated in the Regulation, domestic distribution systems should not cause contamination of public or private drinking water supply systems with deposits, harmful water or undesirable substances, irrespective of their design or construction. A choice of proper protection is possible after a thorough assessment of the risks in the draw-off point requiring protection against contamination caused as a result of reverse flow [4].

Conditions of supplying water intended for human consumption and rules of creating conditions for ensuring proper quality of water are governed by the Act of 7 June 2001 on Collective Supply of Water and Collective Sewage Treatment [14] (Article 5), according to which: “1. A water supply and sewage treatment company is obliged to ensure the ability of water supply and sewage devices possessed by such company to supply the required amount of water under an adequate pressure and to supply water and treat sewage in a continuous and reliable manner, and to ensure that the supplied water and treated sewage are of proper quality.

1a. A water supply and sewerage treatment company is obliged to conduct regular internal controls of water quality.”

Requirements concerning hot tap water are contained in the Regulation of the Ministry of Infrastructure of 12 April 2002 on Technical Conditions Buildings and their Location Should Meet [8]; they are, however, only requirements concerning water temperature, as cited below (§ 120): ”A domestic hot water distribution system should enable to obtain water with the temperature not lower than 55°C and not higher than 60°C in draw-off points”.

That Regulation regulates requirements concerning the amount of thermal energy needed to prepare such water, i.e. such amount should be maintained at a reasonably low level and devices for preparing hot water installed in buildings should meet requirements concerning energy efficiency.

According to the Regulation of the Minister of Economy of 15 January 2017 on Detailed Conditions for Heat Distribution System Operation [8], describing, among others, the way heat is sold (§ 2), ”A heat distribution company – energy company producing heat in sources of heat exploited by such a company and transmitting, distributing and selling heat produced in those sources or purchased from another energy company”.

So, heat distribution companies are suppliers of heat in the form of heating medium serving for heating tap water and are responsible for thermal energy parameters. Heating is effected using a diaphragm on devices in which only the process of heat exchange takes place between the heating medium and heated water which in normal conditions of operation excludes the contact of the heating medium with heated tap water. The cold water supplier is responsible for the quality of heated tap water; however, the influence of the condition of the domestic distribution system of the building for which its owner is responsible is not without significance.

The principles of using residential buildings with all their systems and technical devices are governed by the Building Law [12] of 4 July 1994 (JL no 1409 of 2013 as amended) and the Regulation of the Minister of Internal Affairs and Administration of 16 August 1999 on Technical Conditions of Using Residential Buildings [9].

According to Article 5(2) the Building Law [12], „A structure should be used according to its intended use and environmental protection requirements and maintained in proper technical and aesthetic conditions, not allowing that its utility capabilities and technical efficiency be deteriorated, especially with regard to requirements referred to in Point 1 (1–7)” including „adequate hygienic and health conditions and environmental protection”.

According to § 3 of the Regulation of the Minister of Internal Affairs and Administration of 16 August 1999 on Technical Conditions of Using Residential Buildings [10] (JL.99.74.836, JL.09.205.1584): “ ...domestic hot tap water distribution system – hot water pipework in a building along with its fittings and equipment which begins in the place in which the pipe is connected to the valve cutting off such a system from the heating substation or connection and ends in hot water draw-off points; such a system also includes a local hot tap water distribution system". Moreover, §13(1) gives the conditions for and the manner of using technical devices and systems as well as products used for repairing and maintaining them which should not deteriorate the utility capabilities of the medium supplied through such devices and systems. According to Point 2, "technical and functional parameters of the medium supplied using the technical devices and systems to flats and rooms intended for common usage should be in line with values of parameters specified in separate regulations and relevant designs of such devices and systems". Chapter 8 § 28 of that Regulation regulates using a hot tap water system according to which: "The hot tap water system should, in the period of using water, enable the possibility to supply it with the temperature defined in separate regulations to draw-off points according to the conditions of using it, as assumed in the design".

3. Corrosive factors

The most important parameters which determine the intensiveness and rate of corrosive processes include [2]:

- **temperature** – this has a decisive influence on the effect of corrosive destruction of metals. On the one hand, it changes the concentration and even the composition of water, and on the other hand, it causes the increase of the degree of dissociation and a considerable rise in the movement of ions. This results in the decrease of the value of pH reaction. It has been determined that with an increase in the temperature of 1°C pH falls by 0.01. Additionally, the temperature rise increases the rate of diffusion of oxygen to the surface of metal; however, its solubility decreases. At a temperature > 80°C, a fall of the corrosion rate is observed. This phenomenon is connected with the occurrence of two processes: the increase of the corrosion rate with the rise in the temperature and at the same time the decrease of the insolubility of oxygen with the fall of the temperature of the system, and this process, after it exceeds a temperature of 80°C, obstructs the influence of the temperature factor. In closed (pressurized) systems from which oxygen cannot be released, the corrosion rate increases with the rise in the temperature up to the total absence of oxygen in water.
- **content of oxygen dissolved in water** – such parameter has a variable influence on releasing Fr(II); and the higher the content in tap water, the larger is the corrosion rate,
- **water pH** – numerous tests show that a higher value of water pH limits the rate of iron release; pH increase affects the rate of Fe(II) oxidization and limits the solubility of $Fe(OH)_3$ and iron carbonate,
- **alkalinity of water** – higher alkalinity limits corrosion but in some cases the occurrence of "red water" was also observed when the alkalinity of water was increased,
- **content of free carbon dioxide in water** – the smaller the amount of CO_2 in water containing oxygen, the lower the rate of releasing iron compounds.
- **salinity of water** – a high concentration of Cl^- and SO_4^{2-} ions increases the corrosion rate and some papers indicate that the increase of the corrosion rate is seen with the rise in the temperature of water; additionally, a higher concentration of nitrates will affect

the increase of releasing iron in chlorine-disinfected water; in oxygenated water, the release of iron is inhibited by insoluble ferric hydroxide oxides, calcium carbonate and siderite which form a protective layer hindering diffusion of Fe(II) ions,
- **stagnation of water in pipework** – this usually causes a fall in the oxygen content and an actual risk of the occurrence of "red water".

Analysing the above, it may be found that corrosion is limited (but not eliminated) by higher alkalinity of water and higher pH. Chlorides and sulphates create favourable conditions for corrosion, the lower the alkalinity of the water. Waterworks stations taking surface water should consider the fall in the alkalinity of the water which takes place in summer. Stagnation of water in pipework leads to releasing relatively large amounts of Fe(II), which, after the following flow, may result in "red water". Reports also show that when pipes have already been corroded, good water oxidization prevents such phenomena.

A proper protection against corrosion should include, above all, the identification of the cause and determination of the corrosion rate. On that basis actions undertaken to prevent and slow down the corrosion should be defined. Maintaining an appropriate pH reaction and the equilibrium of carbon and calcium as well as the adjustment of alkalinity of water prevent excessive corrosion of the network and protect against the creation of so called rust-coloured water. No water component remains unreactive to metal and each may speed up or slow down corrosion. The rate of corrosion is determined by interaction of protective and corrosive components contained in water. Water corrosivity in most cases is identified with its aggressiveness, which is not correct. Aggressive waters, indeed, are always corrosive but nonaggressive waters may also be corrosive.

4. Methods of assessing the aggressiveness of corrosive water

There are many indexes (Langeliera, Ryznara indexes or Strohecker formulas) used to assess the corrosivity of water but due to the complexity of the corrosion process, none of them ensures the full assessment of the rate of corrosion taking place in water environment [2]. Due to the common usage of galvanized steel pipes in hot and cold water systems, the values of the above-mentioned indexes were regarded as a good basis for forecasting the durability of system materials. As the range of materials used in domestic distribution systems has been significantly extended, it has become necessary to create the proper material selection system based on the knowledge of the degree of corrosive aggressiveness of tap water which will be supplied to a given system. Standard PN-EN 12502 [6]; Protection of metal materials against corrosion, is helpful in this. Guidelines to the assessment of the risk of corrosion in water distribution and storage systems. According to such document: "corrosion is a result of interaction between various factors, its volume may be only expressed as a risk of the occurrence of corrosive damage". The document is, thus, a guide and it does not contain any principles for using various materials in water supply networks. It may only serve to decrease the risk of the occurrence of corrosive damage by:
- helping to design, install and operate systems with regard to anti-corrosion protection,
- assessing the need of additional protection against corrosion for new and already operating systems,

- helping with analysing the causes of failure to prevent its recurrence.

The risk of corrosion caused by the impact of water is determined by indicators S_1, S_2. Indicator S_1 determines the risk of pitting corrosion [5];

$$S_1 = \frac{c(Cl^-) + c(NO_3^-) + 2c(SO_4^{2-})}{c(HCO_3^-)} \qquad (1)$$

when:

$c(Cl^-)$ – concentrations of ions Cl^-,
$c(NO_2^-)$ – concentrations of ions NO_2^-,
$c(SO_4^-)$ – concentrations of ions SO_4^{2-},
$c(HCO_3^-)$ – concentrations of ions HCO_3^-.

Concentrations of specific ions are expressed in [mmol/dm^3]. The risk of pitting corrosion increases with an increase in the value of S_1:

If $S_1 < 0.5$ – the occurrence of pitting corrosion is unlikely and very likely for $S_1 > 3$. Bicarbonate and phosphate anions combined with calcium cations may behave like cathodic inhibitors. Concentrations necessary for that purpose are:

$$c(HCO_3^-) \geq 2.0 \frac{\text{mmol}}{1}, cCa^{2+} \geq 0.5 \text{ mmol/1}$$

Stagnation of water and sudden changes in temperature contribute to the occurrence of pitting corrosion. If water in cold water pipes after overnight stagnation in the room temperature is replaced with water with lower temperature, corrosion products tend to come off.

The value of parameter S_2 shows the risk of selective corrosion:

$$S_2 = \frac{c(Cl^-) + 2c(SO_4^{2-})}{c(NO_3^-)} \qquad (2)$$

when:

$c(Cl^-)$ – concentrations of ions Cl^-,
$c(NO_3^-)$ – concentrations of ions NO_2^-,
$c(SO_4^{2-})$ – concentrations of ions SO_4^{2-}.

It is thought that the susceptibility to selective corrosion is low when the value of S_2 is below 1 or above 3 or when $cNO_3^- < 0.3$ mmo/l.

The conditions of system operation have no significant influence on the selective corrosion process but the effects of selective corrosion significantly affect water quality. The amount of dispersed solid particles of corrosion products which may be removed from pipe walls depends on the time of slow water flow and the volume of sudden turbulent flow. With the progress of the corrosion process, the colour of corrosion products changes from grey to brown.

The above indicators do not consider many parameters determining the corrosive nature of water; in practice, they are used for a "rough" assessment of the chemical stability of the water. Unstable water causes the accretion of calcium carbonate deposits on pipes and contributes to the occurrence of deposit corrosion, whereas corrosive water destroys pipes and contaminates them with corrosion products.

5. Summary

The main causes of operational problems arising from secondary contamination of tap water due to its corrosiveness are connected by factors including the instability of the quality of water supplied to consumers, the technical condition, configuration and plumbing conditions of the network (pressure changes), heating substations and domestic distribution systems. The lack of chemical stability of tap water may be caused by many factors, mainly the deteriorated quality of raw water (which results for example from low water level, long periods of high temperatures or lack of precipitation), the application of large doses of coagulant and lack of pH correction as well as possible disruptions in the automatic administration of reagents, etc. Stagnation of water and changes in temperature, the flow rate and pressure intensify the phenomenon of corrosion. At the same time, the occurrence of the above-mentioned circumstances combined with instability of the chemical constitution of water may cause corrosion and corrosion products coming off pipe walls which result in secondary contamination. That is visible in hot tap water system mainly in places in which the flow rate falls (heating) and water is accumulated (in tanks) as well as in final points of the cold water system, thus causing operational problems connected with the occurrence of "red water".

This problem could be solved if water treatment plants performed obligatory analyses of water quality with regard to its corrosive aggressiveness. A solution to this problem may be achieved by introducing additional legal requirements which would explicitly determine criteria and limits of tap water corrosivity to avoid consequences connected with water reaction to elements of domestic distribution systems and water supply networks. This paper suggests the possibility of using indicators S_1, S_2 and Langelier and Ryznar indexes in the assessment of the corrosive aggressiveness of water. That determines the quick identification of causes of water quality deterioration, enabling to avoid possible operational problems.

Technical actions preventing the occurrence of secondary contamination of water in domestic distribution systems include: the necessity to fix fittings protecting against contamination supplied from the water supply network on the cold water inlet to heating substations (mechanical filters) as well as fittings ensuring the possibility to rinse by-passes in heating substations, conducting regular assessments of domestic distribution systems and keeping them in a proper technical condition, maintaining a constant circulation in hot tap water systems in buildings and stabilization of pressure in the water supply network. It is essential to optimize the selection of materials of pipes, fittings and devices in the network, heating substations and domestic distribution systems depending on water composition, and to successively apply high-quality materials and fittings which are resistant to corrosion. Due to the undeniable influence of failures in domestic distribution systems and water supply networks, attention should be paid to the quality of work performed and the following of the regime during resolving the failure in the water supply network. Additionally, there is significance in the strict cooperation between water supply and heat distribution companies' services, domestic distribution system users and building owners with regard to the prevention of water quality deterioration in domestic distribution systems and avoidance of problems connected with such deterioration.

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