

Causes of hot and cold water system failure

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Abstract. The paper presents causes of the failures of hot and cold water systems. Most often they occur in the case of installations built with metal pipes and result from the use of improper materials and the adoption of wrong solutions. Failures are caused by chemical and electrochemical corrosion resulting from design and manufacturing errors. Further on, the corrosion process is briefly described. The most common causes of corrosion of hot water installations are discussed and examples of them are presented. On the basis of observations it can be stated that despite the knowledge about corrosion of hot and cold water installations, some of the them are improperly designed and constructed and exhibit high failure rates. The summary discusses the most common errors for different installation solutions.

1 Introduction

The cold and hot water systems failures, resulting in more or less intense water leaks are common for all buildings in use. Most often the leakage in the installation are not dangerous for people, but can be a nuisance especially when repairs require total or partial shutting off water in the facility. At the same time, they can cause significant damages. An example of a typical water leakage is shown in Figure 1.

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Fig. 1. Water leakage in a hot water system.

The analysis of the existing failures shows that the main causes of these failures are:

- improper quality of materials used,
- chemical corrosion of pipes,
- electrochemical corrosion of pipes,
- selective leaching of fittings and valves,
- mechanical damage to the system components.

Table 1 below presents a summary of leakages in hot and cold water systems between 2014 and 2016 in an residential building (eleven gates, four storeys) in Szczecin, which was put into service at the end of 2009. The water systems were made of galvanized steel pipes.

Table 1. Water leakages in particular years.

Lp.	Year	Cold water system	Hot water system	Total
1	2014	4	1	5
2	2015	2	4	6
3	2016	7	1	8
	Total	13	6	19

It can be seen that there have been more cold water than hot water failures in this building, opposite to the typical distribution.

Cold and hot water system failures have always been a problem in systems made of galvanized steel pipes [1]. As a popular method for setting up water systems, there are still many of them in use to this day. It is important to pay attention to the problem of corrosion and possible ways to limit it. Proper maintenance allows to extend the service life and potentially reduce costs.

2 Failure causes

2.1 Improper quality of used materials

Cold and hot water systems used to be made of galvanized steel pipes with thick zinc layer. The frequent occurrence of plastic pipes in water systems allow to reduce the leakage caused by material defects. The author has several years of evidence of improper quality of galvanized steel pipes. An exemplary cross-section of a pipe of improper quality, found at the place of leakage, is shown in Figure 1.

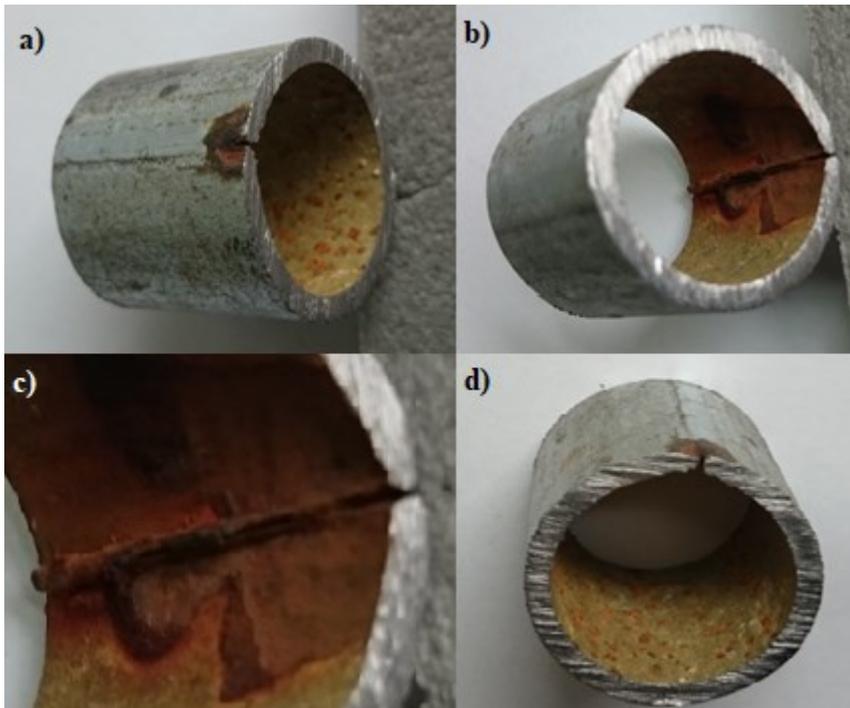


Fig. 2. Cross-section of improperly welded pipe a) view from the outside b) from the inside, c) close up, d) from the front.

In the analysed case, the leakages started to occur frequently after four years of operation. Leaks occurred on the pipe weld. The cross-sections show that there is a point and sectional lack of weld due to lack of material in the leakage areas. As it was concluded above, it is most likely that in the places where the leaks occur there was metallurgical scale, in the initial period it sealed the pipe. During operation, flowing water caused its leaching and after some time leaks started to appear in places where scale was present.

2.2 Chemical Corrosion

Chemical corrosion is a type of corrosion caused by the action of chemical substances without the influence of electrical current (electrons are transferred directly between oxidized metal and oxidant). The occurrence of chemical corrosion in water systems operating at higher temperatures has been a subject of publication in various journals and books. Technical equipment operating on hot water systems requires treated water, to avoid the influence of

aggressive oxygen and salts. Water treatment needs to be performed using tested equipment using e.g. desalination methods. Such systems reduce or eliminate the occurrence of the chemical corrosion.

In case of installations operating on hot water with temperature between 15 and 100°C it is possible to use small amounts of chemical and electrochemical agents. Tap water regulations strictly regulate the properties and content of those agents. In accordance with the law the tap water properties cannot be changed considerably [2].

The hot water systems for preparation and distribution of tap water are primarily susceptible to corrosion. Particularly due to various interactions and corrosion deposition that is insoluble in water. The corrosion intensity in those systems is hard to evaluate. Different pipe damages caused by corrosion and corrosion deposition are shown in Figure 2. Probable cause lies in the temperature of water that results in the production of zinc oxide residue. The oxide acts as an anode, while under the elevated temperatures inverts the polarity towards iron, causing extensive corrosive damages.



Fig. 3. Corroded hot water system pipes a), b) corroded pipe ruffling, c), d) corrosion deposition on the inner surface.

People needs regarding quality and comfort of using hot water systems increase periodically. For proper durability of hot water systems, they should operate on 45 to 50°C water. Such temperatures are suitable for showers and baths. For all modern laundry detergents, high water temperature is also unnecessary. The extend of the corrosion increases with temperature in all hot water systems.

The regulations [3] require that the temperature of hot water at the point of consumption is not less than 55°C and not more than 60°C. The process of corrosion is relatively slow at 45-50°C, whereas it has been observed that the rate of corrosion increases drastically between 60 to 65°C. When the temperature is further increased to 70°C and above, additional complex

corrosion processes occur, which can lead to rapid and thorough corrosion of pipes. This applies especially to galvanized tanks and pipelines.

Raising the temperature to 70°C results in an predictable increase in the intensity of corrosion in iron and copper pipes. However, for galvanized steel pipes and tanks things are different and less unequivocal. The behaviour of galvanized iron at these temperatures depends on the type of water. In the literature much is written about the change in the potential of zinc at temperatures from 60°C to 70°C. This phenomenon is treated as the main cause of increased corrosion. However, the change of the zinc potential can only take place in the presence of iron, i.e. only after the damage of the zinc coating. It should be added that zinc at higher water temperatures, especially in the range of 60 to 70°C corrodes much faster than at lower temperatures. This is due to the fact that the oxide deposits formed at lower temperatures are compact and protect the zinc against further corrosion, while at higher temperatures they have a loose structure and are washed out by water [4]. The progress of dissolving the zinc layer inside the pipes that takes place during the operation of the hot water installation was determined. Figure 3 shows the condition of zinc on pipes after nine years of operation.

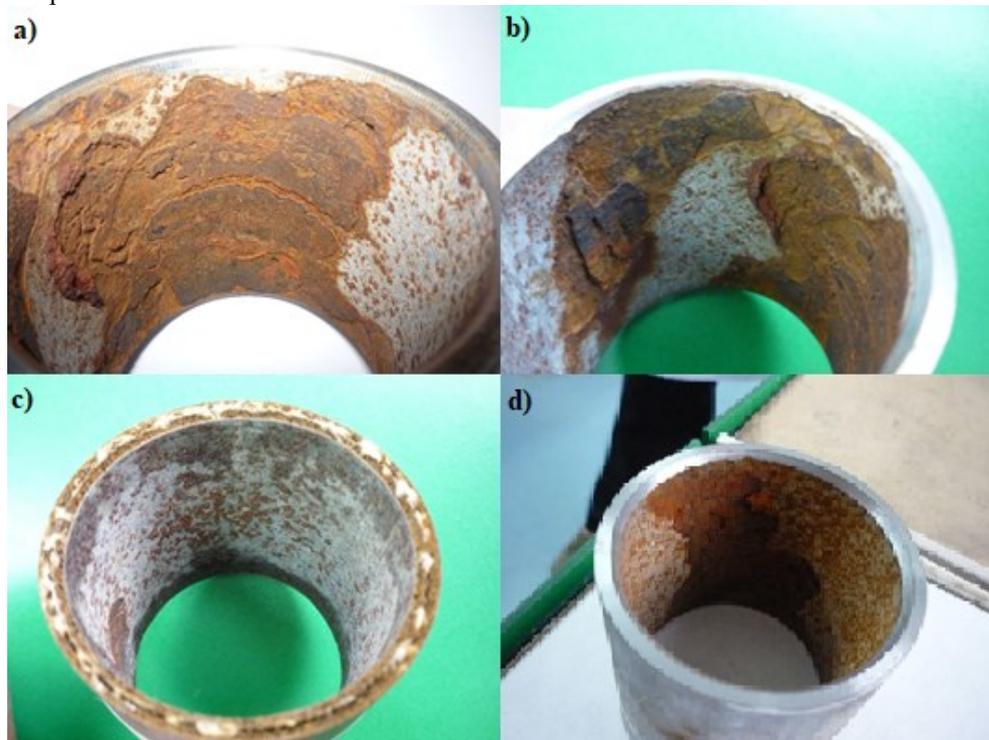


Fig. 4. Condition of zinc coating and pipe inside pipes after eight years of operation a) surface corrosion of the pipe - deep corrosion, b) surface corrosion of the pipe - deep corrosion, c) several small corrosion centres d) surface corrosion of the pipe - shallow corrosion.

Based on the presented photos, it can be noticed that the zinc coating defects can either be on a surface as a whole or have several centres. In accordance with PN-EN 10240: 2001 pt. "Internal and/or external protective coatings for steel tubes - Requirements for hot dip galvanizing coatings in automated galvanizing plants"[5] for pipes with water intended for human consumption, the thickness of the zinc layer on the inner surface of the pipe should be at least 55 µm. Following condition is certainly not met by the presented pipe sections.

Water treatment can also be performed with use of magnetizers. The magnetizer consists of a cylindrical body (pipe) with magnets inside. The water flowing through the device crosses perpendicularly the magnetic field created by the magnets. Under the influence of this field, the metallic molecules and dissolved salts change their electrophysical properties. However, water remains intact. Calcium, magnesium, silicate, etc. salts do not precipitate in the form of compact deposits on the walls of pipes but form a fine crystalline sludge. Traditional sludge (in the process of heating or CO₂ imbalance) is carried by the liquid current outside the installation or deposited in dead spaces creating easily removed layers. Electrolyte molecules exposed to magnetic field that get into contact with other molecules transmit their charges to them. It allows to remove old layers of limescale from the installations.

Magnetizers reduce deposition, but do not change the chemical properties of water, including its corrosivity. Taking this into account, it can be concluded that the lack of magnetizer in the installation is not the cause of its corrosion, but influences the amount of limescale.

Corrosion of hot water preparation and distribution systems and deposition of limescale has always been a problem in installations made of galvanized steel pipes [6]. At the turn of the sixties and seventies of the last century, a large number of failures of hot water systems made of galvanized steel pipes in Poland was caused by corrosion resulting from water overheating. Many installations and systems of hot water preparation, which in the past were made of steel pipes, exist and work to this day. Therefore it is necessary to pay attention to the problem of corrosion and possible ways of limiting it. This will allow them to extend their service life and reduce the costs of maintenance.

2.3 Electrochemical corrosion of elements

Electrochemical corrosion of metal pipes is caused by the transfer of electrons in aqueous solution between two metals with different electrochemical potentials. In the corrosive centres the lower potential metals acts as anodes - they are subject to oxidation, which product is transferred to the solution. In the case of steel pipe installations, it usually occurs when parts are replaced by copper.

The rules of combining different materials in one heating circuit are described in the Polish Standard PN 93/C 04607 "Water in heating systems - Requirements and tests concerning water quality"[7]. These requirements can also be applied to hot water circulation circuits.

According to the above standard, copper and steel can be combined in central heating installations under certain conditions. If the sum of chlorides and sulphates in the operational water is less than 50 mg/l, these interaction can be used without any restrictions (e.g. copper pipes and steel radiators). However, if the sum is greater than 50 mg/l, a suitable corrosion inhibitor must be used to limit the corrosive actions.

A different problem occurs in systems which combine copper, steel, galvanized steel (or aluminum). As a result of direct interaction of these metals, electrochemical centres are formed and cause a rapid dissolvment of iron and zinc. This phenomenon is prevented by the use of insulating spacers between different metal sections. Iron and zinc corrosion also occurs when copper ions are present in the water (derived from the corrosion of copper sections). The ions stick to the surfaces of these metals causing an intense corrosion build-up. Therefore, steel and copper pipes must not be connected in closed water circuits (circulatory) of domestic hot water systems. Hot water plate heat exchangers soldered with copper [8] should not be used either. Interaction of those metals in an operating hot water system requires a proper section order. The copper sections must always be installed behind the steel sections according to the direction of water flow [9].

In some cases the corrosion products of steel pipes may break away from their surface and mechanically damage the copper oxide layer protecting it against corrosion, increasing the corrosion rate. For this reason, it is preferable to use a single metal installation, which protects it against corrosion in the most effective way.

Figure 5 shows fragments of the installation in which corroded fragments of galvanized steel pipes were replaced with copper pipes causing further corrosion.

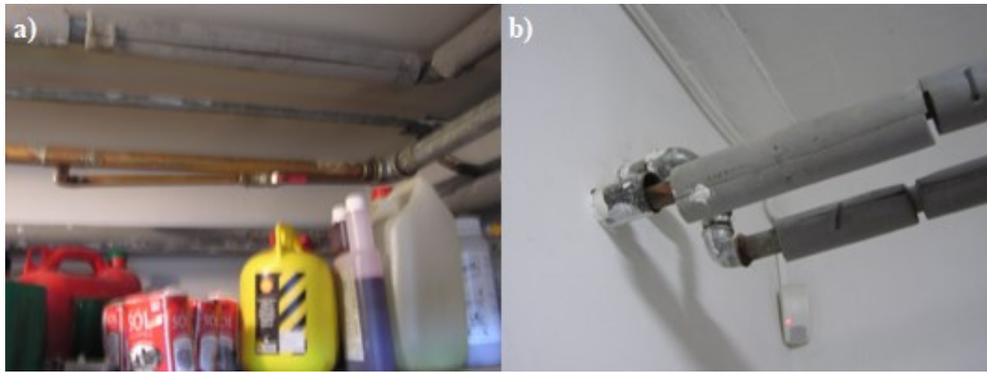


Fig. 5. Replacement of corroded steel pipes with copper pipes.

A typical elastic connection was made of the ZAMAK alloy. This alloy consist mostly of zinc, but also has a several percentage content of aluminum and copper. The ZAMAK alloy is a perfect material for a mass scale production of precise elements e.g. in a hot chamber die casting methods. However, connections made of ZAMAK alloy installed on brass or steel sections start to corrode due to electrochemical processes. Such elements quickly exhibit alloy stratification. Occurring leakages are caused by high pressure of detached corroded parts.

2.4 Selective corrosion

In case of a selective corrosion one of the components of a metal alloy is removed due to corrosion processes. The majority of Polish fittings and ball valves used in hot and cold water installations are made of brass $\text{CuZn}_{39}\text{Pb}_3$ or $\text{CuZn}_{40}\text{Pb}_2$ recommended in the PN-EN 1254 part 1-7 [10]. The same brass grades are recommended in PN-EN 13828:2005 [11].

In both these standards, a statement is made that the materials used should be resistant to dezincification. Dezincification of brass, which is an alloy of copper and zinc, occurs when due to the corrosion, the zinc is selectively removed leaving a porous copper structure with low strength. The process shows itself as a change of colour of the alloy (from yellow to red).

The risk of selective corrosion of brass is largely related to its microstructure. The microstructure of brass depends on the mechanical and thermal treatment of the product, and also on the copper content of the alloy (the higher the copper content, the less susceptibility of the alloy to dezincification). Brass can be additionally protected against dezincification by introducing small amounts of lead (Pb), tin (Sb) or arsenic (As) into the alloy. The mentioned standard PN-EN 13828:2005 [11] states that "copper-zinc alloys containing more than 10% zinc are exposed to galvanization under the influence water inducing galvanization".

According to the standard, PN-EN 12502-2, "Protection of metallic materials against corrosion. Risk of corrosion in water-conducting systems"[12], water causing galvanization of brass is characterized by low content of bicarbonate ions, high content of free carbon

dioxide in relation to bicarbonate ions and increased content of chloride, sulphate and nitrate ions in relation to bicarbonate ions (their values were not specified in the standard).

More than 70% of the water supply in the country may cause galvanizing of brass. This is problematic considering that majority of the brass elements on the market are not resistant to galvanizing (DZ or DZR type). In most other EU countries the elements are made of bronzes - alloys Cu-Sn-Zn-Zn - which are resistant to such corrosion under water influence, e.g. alloys $\text{CuSn}_5\text{Zn}_5\text{Zn}_5\text{Pb}_5\text{-C}$ or $\text{CuSn}_3\text{Zn}_8\text{Pb}_5\text{-C}$, which according to EN 1982 are recommended for making ball valves for water supply systems in buildings [6].

3 Failure susceptible parts

Currently, the most failure susceptible elements are the flexible connections for connecting fittings and components of cold and hot water systems. They are made in the form of rubber hoses in a metal braided sleeve with connection terminals. They significantly shorten the time of connecting sanitary utensils to the installation. Such connection is easy to make and does not require any special tools.

Initially, the rubber hoses in metal braided sleeving were manufactured with internal sleeves made of brass, stainless steel or PPSU plastic.

With time, cheaper hoses with internal sleeves manufactured in Asia, made of the previously characterized ZAMAK alloy, appeared on the Polish market. After a few years of operation, they cracked, especially in hot water installations. They often resulted in tearing off the connection nut from the flexible connector and, as a result, to failure, and thus to flooding and significant material damage. Most often such failures occur in the case of a hydraulic impact in the network or at night, when the pressure in the system increases due to lack of water intake [13, 14].

ZAMAK at low temperatures retains its tensile strength and hardness. It turned out that at a higher temperature (corresponding to the temperature of hot water in the installation), those characteristics drastically deteriorate. It becomes brittle and cracks into small pieces when the connection nut is pressed harder. This material should not be used where there are also high dynamic loads (e.g. hydraulic impact). Moreover, the place of contact of this alloy (zinc, aluminum) with steel or copper or brass installation is susceptible to electrochemical corrosion.

In addition, the material due to low cost of production is also used by some Asian producers to build cheap fake branded angle valves, batteries and fittings.

Flexible connections made of ZAMAK alloy were offered with aluminum braid. In the manufacturer's recommendations included in the technical card attached to the product, it was important to replace them every single year. Stainless steel braided tubes are recommended to be replaced every 10 years. It should be recalled that it is assumed that the durability of the installation (pipes) is 50 years.

Hundreds of thousands of such hoses were installed in Poland within a few years. They cracked and caused severe damage. After several lawsuits for compensation for damages in flooded buildings, manufacturers withdrew from the use of this alloy and returned to PPSU, brass or stainless steel sleeves [14].

4 Summary

In the introduction, the most important reasons for the failure of cold and hot water systems are given. The observation shows that the most common cause of system failure is corrosion of pipes or fittings. Improper quality of materials used to make the installation or mechanical damage to the system components are also to be blamed.

The individual causes of the failure are discussed in more detail in following chapters. Defects of steel pipes used in installations resulting from errors in the production process are discussed. Basic information concerning corrosion of materials from which elements of cold and hot water installation are made is presented. The examples of execution faults are presented. On the basis of the observations it can be stated that despite the knowledge about the corrosion of the installation, some of them are still improperly made and repaired.

The most common mistakes are:

- low quality of the components of pipes and fittings used in the system,
- connection of copper and steel elements in circulating circuits, e.g. replacement of steel pipe parts with copper or use of copper soldered plate heat exchangers,
- the use of water system components made of untested materials.

Galvanized steel pipes are not suitable for hot water pipes. In German guide for designers and installers [1] we can find that "they are not suitable for hot water installations because they can corrode strongly at temperatures around 60°C".

In Poland, galvanized steel pipes for hot water installation are becoming less common, slowly being replaced by stainless steel, copper and plastic pipes: PEX polyethylene, polypropylene and polybutylene.

Inferior materials or improper material change introduced during the repair of failures of cold and hot water systems can lead to increased failure rates and significantly shortened operating life of the system, as well major difficulties in the use of cold and hot water systems by residents.

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