Effect of material and water quality on disinfection and risks of corrosion

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Summary
Disinfection of drinking water is generally avoided in Denmark and the original ground water is treated as little as possible. Correct design, material quality and process control are therefore important to avoid problems for the consumers – such as corrosion, increased metal release, microbiological influenced corrosion (MIC) of stainless steel, pathogenic microorganisms like *Legionella*, and growth of unwanted microorganisms introduced by ingress of polluted water.

In the future more groundwater wells are expected to be closed down due to increased levels of contaminants and as a consequence the drinking water sources will be reduced. Introduction of alternative water sources is therefore considered, whereby water treatments and potential disinfection may be necessary either at waterworks or locally at the consumer. Very hard water is common in Denmark and softening or partially desalination of the hard water types are considered, as is merging very different water from waterworks thereby mixing hard and softer water types. Introducing different water types in the distribution network and mixing different water types may cause threats in terms of microbial growth and more corrosive water.

Over the last 30 years the use of stainless steel and polymer materials has steadily increased in drinking water installations and today almost all installations in Denmark are built with pipes of these materials. In other European countries copper pipes are still widely used, whereas the use of hot dip galvanised steel pipes is decreasing. The current evaluation of material integrity is linked to geographical areas of typical water types and component approval testing. To secure the integrity of existing and new installations, issues of corrosion and possibly also disinfection options must in the future be elucidated under conditions of changed water qualities. This introduces the need for e.g. a mobile test facility supplying the option of monitoring effects of water quality variations on corrosion properties, metal release, biofilm growth, MIC, and also to test performance of specific components or water treatments under varying conditions.

Introduction

Drinking water in Denmark is presently based entirely on ground water resources of high quality. The composition of the water is, however, very different in the separate regions, and the hardness is very high in some areas (Fig. 1). The water is at least 30 years old and the content of dissolved organic matter is generally low. Basically only aeration and rapid sand filtering are necessary treatments, and disinfection of drinking water is generally avoided. Correct design, material quality, component approvals and process control are therefore crucial to avoid problems for the consumers such as corrosion of installations, increased metal release, microbiological influenced corrosion (MIC) of stainless steel, pathogenic microorganisms like *Legionella*, and growth of unwanted microorganisms introduced by ingress of polluted water.

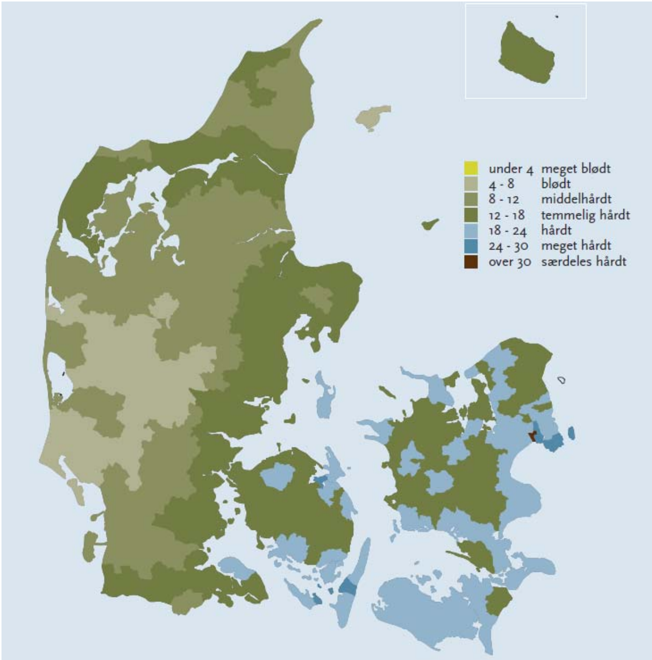

Fig. 1. Map of water hardness averaged for regions, numbers given in °dH. Data from 2002 [1].

In the future more groundwater wells can be expected to be closed down due to increased levels of contaminants and as a consequence the drinking water sources will be reduced. Introduction of alternative water sources such as surface water or desalinated water is therefore considered, whereby water treatments and potentially disinfection may be necessary. Merging water from different waterworks of very different water types, e.g. hard and soft water types, could be introduced. Softening or partially desalination of the hard water types are also considered to reduce the amounts of calcareous deposits, thereby providing benefits for the consumers in the form of longer service life time of e.g. appliances and energy savings. Softening is presently only allowed for warm water systems in domestic installations and for industrial applications. The future changes of water quality may be a challenge to the existing installations and for withholding the current disinfection strategy.

This paper focuses on the research and test programme necessary for evaluating the consequences for installation integrity of 1) changing the water quality to less ground water and more treated water types and 2) disinfection by central or local disinfection methods. Before changing the water system, interaction between materials, corrosion and disinfection must be elucidated to ensure reasonable service lives for existing installations.

Materials

In Denmark the materials are chosen according to the water quality in the geographical area of installation. The aim is to preserve the good quality product through the distribution system and domestic installations to the consumer's tap as stated in the EU drinking water directive from 1998 [2]. In Table 1 an example of selected water quality parameters from Regnemark water works in the Copenhagen area is given together with the official limit values valid for drinking water quality as delivered from the works. Guidelines for material selection for domestic installations are based on many years of experience, and are maintained and adjusted according to new observations and studies of e.g. metal release rates and data on corrosion failures [3]. The rules given below summarise the basic applications related especially to hydrogen carbonate content.

Hot dip galvanised steel :100 mg/L < HCO_3^- < 300 mg/L
Copper :100 mg/L < HCO_3^- < 240 mg/L
Stainless steel :Cl^- < 150/250 mg/L
Polymers :No criteria

Table 1. Selected water quality parameters of relevance to corrosion.

Parameters	Unit	Regnemark water works, July 2008	Limit values from water work
pH-value (12°C)		7.49	7-8,5
Hardness (total)	°dH	20.0	5-30
Conductivity (12°C)	mS/m	77.4	>30
Chloride (Cl^-)	mg/L	120	250
Hydrogen carbonate (HCO_3^-)	mg/L	384	>100
Aggressive carbon dioxide (CO_2 at 12°C)	mg/L	<2	<2
Sulfate	mg/L	53.5	250
NVOC (C)	mg/L	2,75	4

The distribution network is primarily made from PE, PVC, cast iron and smaller amounts of cement based materials and steel. The use of polymers, especially PE types, is increasing as cast iron pipes are being replaced. In the distribution network the material surface to water volume ratio is low. This means that only little effect of e.g. metal release and migration is expected, provided that residence time is not long. For domestic drinking water installations the use of stainless steel and polymer materials has steadily increased over the last 30 years and today almost all new installations in Denmark are built with pipes of these materials.

The materials traditionally used for these installations are otherwise hot dip galvanised steel, copper for pipes, and copper alloys for fittings. In other European countries copper pipes are still widely used whereas the use of hot dip galvanised steel pipes is also decreasing. The majority of the older domestic installations, especially in apartment buildings are made from hot dip galvanised steel representing an important infrastructure to be preserved even with alternate water qualities. Hot dip galvanised steel corrodes in very hard and chloride rich water types, and likewise very soft water induces a risk of destabilising the existing scale. In this respect lowering the hydrogen carbonate content could be critical, as the corrosion resistance is very much based on carbonate rich deposits and corrosion products, so destabilising this scale (Fig. 2) could give discolouration of the water and particle contaminations. The corrosion resistance is low, if the ratio between the sum of chloride and sulfate ions divided by the hydrogen carbonate content increases, and increasing the chloride content indirectly by e.g. adding hypochlorite could also affect the material durability.

Fig. 2 Hot dip galvanised steel pipes from warm water installations, 40-50 years old. On top half scale has been cleaned off.

The use of copper for piping material is limited in Denmark as the release of copper ions becomes too high in the hard water types (HCO_3^- >240 mg/L). An investigation of copper release from piping in domestic installations [4] showed up to 2369 µg/L copper in samples of 800 ml retrieved after 4 hours stagnation, exceeding the 12 hours stagnation limit of 2 mg/L. The present water types do not induce pitting corrosion in the copper pipes, but if softened water should be applied, this type of corrosion may also occur. Copper release from fittings, valves and meters are also known to initiate corrosion on hot dip galvanised steel, especially being a problem in newer installations of low water usage. Metal release from brass materials does not only include copper, but also lead, as illustrated in Fig. 3. These data show the lead release after 12 hours stagnation from machined test pieces of alfa brass, dezincification resistant brass (DZR) and gun metal. Lead is due to the machining smeared onto the surfaces of the material. The DZR shows an unusual initial behaviour, but generally release significant amounts of lead, and fails in the end of the test by selective corrosion in the grain boundaries.

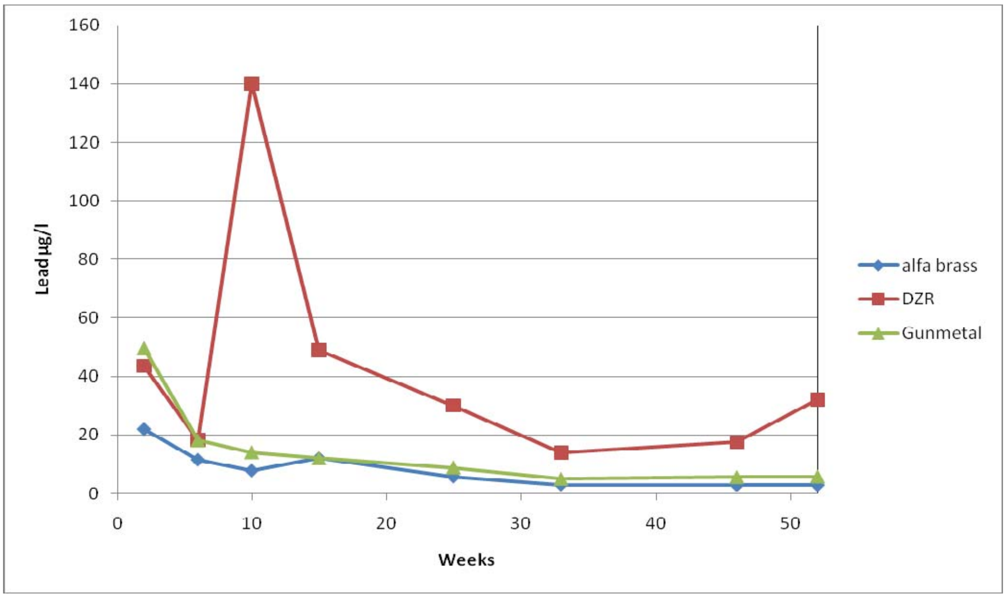

Fig. 3. Lead release after 12 hours stagnation from machined test pieces of alfa brass, dezincification resistant brass (DZR) and gun metal. Average of two data sets.

Stress corrosion cracking, intergranular corrosion and selective corrosion problems on brass fittings and valves mounted especially in new stainless steel installations or polymer installations are increasingly causing expensive water leaks [5]. The failures typically appear in hard water types of high conductivity, in which the brass would previously have been cathodically protected by connection to hot dip galvanised steel. In the new designs being coupled to stainless steel or polymer this protection does not exist.

Stainless steel shows resistance in both soft and hard water types, and the chloride content limit of maximum 250 mg/L is normally not a problem. The number of failures reported on stainless steel pipes of EN 1.4401 is fairly low and metal release insignificant. Microbially influenced corrosion (MIC) is however a risk especially in press fittings, which will be discussed later in this paper. Stainless steel installations are also commonly chosen for critical water distribution systems as in hospitals and public swimming pools, where the level of cleanliness must be high, and welded connections may here be preferred to press fittings.

Polymer pipes of PVC, PE and PEX are used widely for distribution systems and domestic installations (primarily PEX). The resistance and durability is good, but the release of potentially hazardous organic chemicals [6] is a concern. For PE degradation products formed in the polymer like phenols, ketones, and quinines migrate slowly from the material, but in general the concentrations are very low. Another relevant concern is the potential of these materials to facilitate microbial growth by release of organic compounds [7] and the implications for this will be discussed further.

Disinfection in Danish systems

The purpose of disinfection is both to reduce the number of unwanted microorganisms to an acceptable level and control it at this level. For a continuously delivered product like drinking water, the ideal operating mode is clean water constantly. The assimilative organic carbon (AOC) content in the drinking water is approximately 5-20 µg/L, but in some cases higher, which can facilitate aftergrowth of microorganisms in the systems affecting e.g. smell, taste and colour and representing a risk for pathogen bacteria to harbour in a biofilm.

To manage the system without disinfection, awareness must thus be on the following issues:

- Risk for aftergrowth - handled by increased requirements to
    - Water resource – old groundwater
    - Water treatment to produce biostable water i.e. low content of AOC
    - Choice of materials (e.g. polymer pipes and other materials) which should not release growth substrate to any significance
- No disinfection residual
    - More care handling the risk of microbial contamination of the system
    - Lack of experience in handling disinfection in case it is needed
    - Chemicals not ready available
- Risk of corrosion
    - Awareness on MIC of stainless steel
    - Possible higher copper release
- Advantages
    - No formation of disinfection biproducts
    - Less risk of bacterial resistance
    - No “chlorine” taste/smell
    - No corrosion induced by disinfection chemicals

Disinfection with chemicals can, however, be introduced, preventive in relation to new installations, repair work, after long stagnation periods or initiated due to actual bacterial counts exceeding the limit value, but in practice the preferred technique used is to flush the systems thoroughly with fresh water to obtain an acceptably clean system. The full water infrastructure expands from the water works to the tap including huge surface areas covered with natural biofilm, unless the water is heavily and repeatedly disinfected. Previously surface water has been included as an extra resource and added to supplement the ground water in some water works. Chloramines were e.g. used for disinfection, but the critical attitude towards disinfection by chlorine products in the public ended the experiment [8]. The consumers do not readily accept changes in taste, smell or appearance of the water.

Two examples will be given of application of disinfection in Danish water systems. Unfortunately a case of a planned and preventive disinfection for a new stainless steel installation of AISI 304 (EN 1.4301) at a water works went wrong in terms of inducing corrosion. The guidelines [9] recommend a procedure of first cleaning the pipes and then leaving the system for 2 days with a solution made from sodium hypochlorite (NaOCl) in a concentration of 2 L 15 % active chlorine per 1000 L water, checking that adequate residual chlorine is still present, and then flushing with water before checking that residual chlorine content is now acceptably low. However, the system was filled with a solution of 40 L of the 15 % solution per 1000 L water, and afterwards diluted with water to a concentration equivalent to 1500 mg/L active chlorine. The solution was left at around 15-25 °C in the system for only 1 day, but flushing with clean water was not performed until 3 days after.

After just 3 days the first leaks appeared. Corrosion attacks included wall-through pitting especially at the bottom part of the pipes as well as crevice corrosion in the couplings. Corrosion attacks were not especially present at the welds, nor was the material quality questioned. The chloride content in the raw water in this area was approximately 100 mg/L. The added hypochlorite will oxidise microorganisms and organic material and be reduced to chloride increasing the total chloride content. If the disinfection solution is drained from the system, but the system is not flushed with clean water readily, there is a risk that the remains of solution in pools left inside the system is concentrated to even higher chloride contents by evaporation. In this case the applied highly concentrated solution can generate up to 1885 mg/L of chloride and if evaporation concentrates the solution by e.g. 50 %, the chloride content reaches 3770 mg/L. With these concentrations in an oxidising environment, it is in no way surprising that AISI 304 fails by pitting corrosion after a few days. Nor is it surprising that crevice corrosion is also initiated. This case may be extreme, but illustrates that the procedure recommendations for time and concentration- as well as flushing with clean water – must be taken seriously when dealing with oxidising agents introducing chloride.

Another example is a successful case of a local periodical disinfection due to high hygienic criteria in an installation at a university faculty for medicine. A procedure has been found, which ensures that the bacterial numbers stay low and that the material integrity is preserved. The piping is made from stainless steel AISI 316 (EN 1.4401) connected with press fittings of stainless steel. The inlet water is city drinking water with a chloride content of approximately 100 mg/L. The system is disinfected daily by chlorination with 2 mg/L chlorine added as gaseous chlorine. The system is flushed after the treatment and standard drinking water refilled in the system. The entire process lasts 1½ hour. After periods of stagnation or if the total bacterial counts are too high, the concentration for disinfection is increased to 9 mg/L chlorine. This event occurs in average twice a month. No indications of material degradation have been seen after 4 years of operation. For chlorine to be effective towards microorganism a concentration of approximately only 0.5 mg/L is necessary, so the reserve chlorine is used for oxidising also organic material. This process might be optimised by checking the residual chlorine and determining the actual level needed and by perhaps trying to reduce the ingress of organic material e.g. by filtration.

Apart from chlorine based disinfectants, physical treatment techniques like ultrafiltration and UV light [10] could be applied, but presently these techniques are primarily in Denmark applied for industrial water systems. In terms of corrosion no detrimental effects of the treatment to the materials will be expected, but the efficacy of the treatments as disinfection might be affected by e.g. particulate deposits and corrosion products.

The choice of not disinfecting complicates the handling of microbial contaminations. The quality is controlled by periodical analyses of e.g. indicator organism *E. coli*, and if the limit value is exceeded, the water works are obliged to check whether the problem continues, treat the system (flush initially), search for the reason and control again until the limit value criteria are met. The criteria are set for the general bacterial quality in the water phase, even though the original problem may be located in an active biofilm. 94 % of the serious contaminations occur in small water works typically supplying less than 4500 consumers [11]. Microbiological contaminations may also occur in domestic installations. Major variations in water usage resulting in periods of low flow and low exchange of water are common in buildings that are periodically deserted or have too much capacity, e.g. large apartment constructions, vacation houses, and institutions like universities. The consequence may not only be hygienic problems of microbial growth, but also corrosion problems, as dealt with in the following section.

Of special public focus are the approximately 100-130 individuals annually in Denmark contracting the *Legionella* disease. Usually, the cause can be found in the process conditions or design of the warm water system. If the recommended practices of keeping warm water temperatures high throughout the system (minimum 50°C at the tap) and periodically disinfect the system with even hotter water are followed, problems will normally not occur. High temperature does however facilitate a high degree of calcareous deposit formation. Disinfection by chemicals may in some cases be introduced, but if the operating conditions are not changed, then the problem will reoccur.

Material challenges with natural drinking water

Good advice on design and process conditions to handle natural water with low level of treatment includes:

- No dead legs
- Limiting organic carbon sources
- Ensuring circulation and limiting stagnation
- Keeping cold water cold and warm water hot
- Not infecting new virgin systems with unclean water before normal operation

As mentioned earlier some material issues are however especially affected by the strategy of no chemical disinfection: risk of MIC of stainless steel, polymers leaching organic carbon giving potential for aftergrowth, and increased copper release with high total organic carbon (TOC) numbers. The latter could be seen as a positive effect as copper ions are known to limit microbial activity, but the metal release may significantly increase above the limit values. In the following risk of MIC and release of AOC will be further discussed.

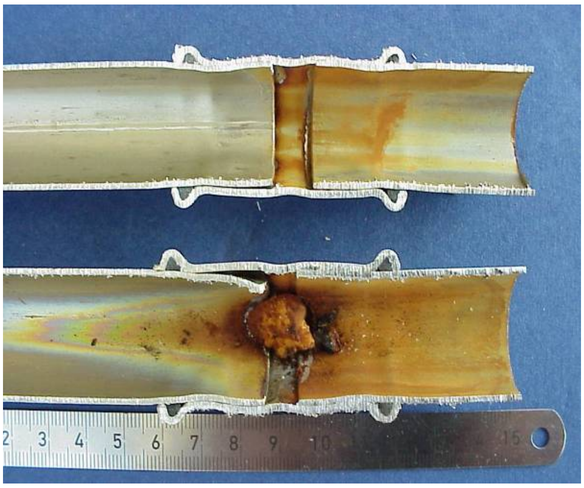

Fig. 4. MIC in press fitting, stainless steel 1.4401 after approximately 1 year exposure.

MIC is a risk for stainless steel press fitting drinking water installations, even though the number of incidents is fairly low [12]. The corrosion attacks occur within 1-2 years after installation in the crevices of the press fitting (Fig. 4). The phenomenon seems to be related to a combination of process conditions favouring growth like stagnationl, incorrect temperatures of cold and warm water respectively, contaminations, and large installations. In an area with several recent cases of MIC, the corrosion potentials were monitored in the domestic installations over a period of 1 year. After a few months potentials increased to a level around +350 vs Ag/AgCl for the cold water (10-15 °C) and +125 for the warm water (approx. 50 °C). This is equivalent to the ennoblement of stainless steel found in natural sea water, which is well documented to be related to biofilm formation. With the current water qualities a natural biofilm will form within 1-2 months, and if the process conditions are unfortunate, MIC may occur. Preventive actions are to follow good practice and recommendations from the producers of pipes and fittings and by operating the system wisely. One design option is to choose gun metal fittings, which supply slight cathodic protection and thereby also dissolving copper ions acting antimicrobially.

From other stainless steel systems like fire protection systems or e.g. service systems in the food industry the problem of MIC is also known. An example is given in Fig. 5 and 6. The case is a heating jacket in type AISI 304, which corroded from the inside at welds after 6 months of operation. Drinking water from a tap at the far end of the plant was used for leak testing, and later the unit was filled with drinking water operated at approximately 25-40 °C for 6 months until leaks appeared.

Fig. 5. Corrosion attack with corrosion products as blister and thin layers of rust spreading from it - starting at the weld. Water side of heating jacket.

Even if the welds could have been of better quality, the recommendation for future use of this type of system is to use water of higher quality and consider which method will work: RO water, cleaning, disinfection by e.g. chemical treatment or UV, filtration, high temperature treatment or whether changing water often and flushing will be adequate.

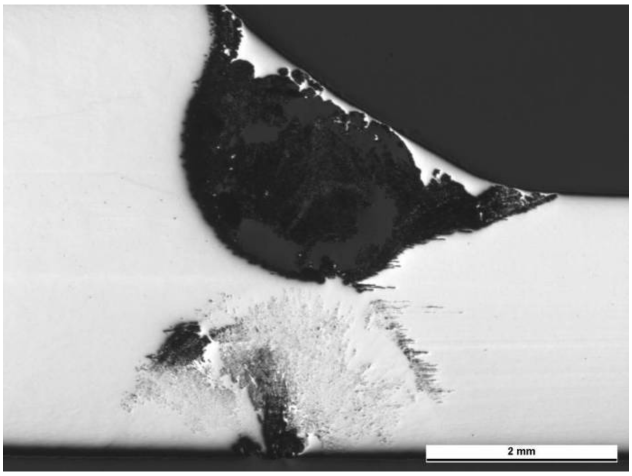

Fig. 6. Cross section through the corrosion attack in Fig. 5. Internal weld pass is fully dissolved by corrosion, the external weld being porous from selective attack in the ferrite phase.

Migration of biodegradable compounds from polymer materials is another specific challenge in a non disinfected system. Work has recently focused on evaluating the risk in the actual systems, and parameters like residence time, surface to volume ratio and polymer material quality studied [7, 13-15].

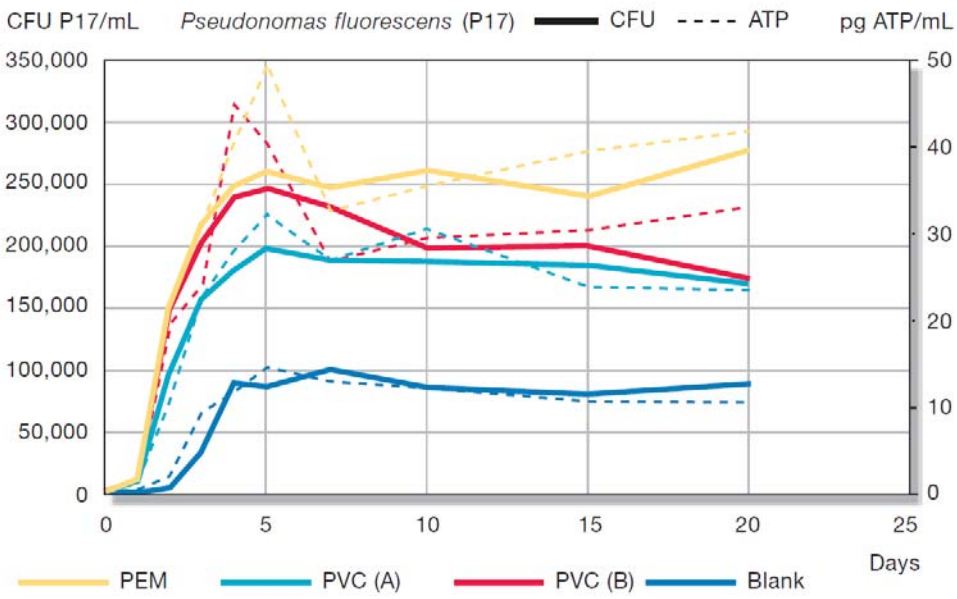

Fig. 7. Growth measured by HPC and ATP of the bacteria strain P17 at 15 °C in drinking water extracts of two types of PVC, a PEM material, and in blank (water alone).[7]

In Fig. 7 an example is given of growth potential in water extracts from PVC and PEM. Some water works deliver water with higher numbers of AOC and especially for these water types the release from the distribution network as well as the installations become very relevant in order to avoid after growth in the systems and deterioration of the water quality at the consumer's tap. The most critical situation appears to be linked primarily to the domestic installations, where longer residence times and higher temperatures could increase the release of assimilate organic carbon as well as the after growth. The release is however quite dependant on materials and test conditions, so standardising the criteria for safe materials or components is an important task.

Tests for risk evaluation

The consequences on the integrity of existing installations of changing water quality to less ground water and more treated water types should be evaluated. Also the possibility that disinfection centrally or locally could be included must be considered. The current available approvals and guidelines are, however, not really designed for this situation, but could be modified. Both the option for testing different water types and the option for evaluating the performance of old installations should be included. In particular studying the effect of changed operating conditions and water types on existing installations is a challenge. It could be handled by installing old material and old product samples with deposits preserved as test objects in test rig designs or by monitoring and sampling directly in the domestic installations.

For determining the long-term behaviour of metals and alloys in contact with drinking water, a European Standard of two parts, EN 15664-1:2008 and pr EN 15664-2, was developed. Experiments carried out according to the operation protocol described in the European test rig standard EN 15664-1 have generated very useful data on actual metal release and corrosion properties of various materials and construction products [17]. Physical and chemical data of the test waters can be generated simultaneously from the water samples retrieved during tests. The water is analysed according to the test design, e.g. every other week, by chemical analysis. Conductivity, temperature and oxygen concentration is monitored on-line. The materials or components tested can be analysed off-line by e.g. metallographic examination and corrosion product analyses.

Test rigs can also simulate operation conditions for e.g. a mixer tap installed in the kitchen at a consumer's drinking water installation. Operation conditions are characterised by rather short flowing and comparably long stagnation periods. The test rig experiments typically run for 26 weeks. Every week the taps are sampled after a stagnation period of 4 hours. This situation is relevant to simulate how prolonged contact between small volumes of water in contact with metal surfaces can lead to e.g. increased nickel contents in the water.

Future test rig studies might also increase the combination of on-line vs. off line techniques. In a previous project on district heating systems test rigs were designed and mounted at different district heating plants [18] and the aim was to demonstrate whether on-line corrosion rate monitoring on carbon steel was possible in low conductivity water [19]. In this setup the use of electrochemical techniques (electrochemical impedance, linear polarisation resistance), weight loss coupons, electrical resistance (ER), and a crevice corrosion cell were tested for corrosion monitoring. Water quality was also monitored on-line measuring pH, conductivity, oxygen concentration and temperature measurements. On-line corrosion potential monitoring, monitoring of corrosion rate by ER and insulating deposit formations have also been demonstrated successfully on zinc probes developed to simulate new installed hot dip galvanised steel in warm water systems [20].

In cooling water systems where biofilm is often avoided by chemical disinfection, on-line monitoring is a strong means to dose biocide or decide when to treat. Electrochemical biofilm sensors [21] can – based on the ennoblement effect on the corrosion potential mentioned earlier in relation to MIC - trace the development of a biofilm in aerobic conductive media. This type of sensor is very useful, if the intention is to clean or disinfect, which will “zero” the signal. The probe is sensitive to low levels of biofilm formation, but in Danish drinking water systems the probe response would probably quickly be saturated by full biofilm coverage, if not cleaned or disinfected repeatedly. However, the option of using techniques like this in test rigs including experimental cleaning/disinfection treatments would be interesting, as the data could be correlated with effects on corrosion properties and bacterial numbers.

Recent work has been done to develop a harmonised test of the biomass production potential (BPP) for determining the growth-promoting properties of construction products in contact with drinking water (CPDW) [15,17]. The assessment of microbial growth potential of CPDW is based on using ATP for determining biomass concentrations in drinking water and on surfaces in contact with drinking water. In 16 week tests under well defined conditions the ATP measurements facilitate the interpretation and show the risk of after growth. Like the EN 15664-1 the test is under defined conditions also in terms of water type and quality, and even if the application of the test will give a much improved approval test for CPDW, it will not directly improve the knowledge on interaction between future water quality changes and material. An alternative test design of a flow system for evaluating growth potential has also been developed and is illustrated in fig. 8. This gives the option of possibly generating more realistic conditions e.g. flow vs. stagnation.

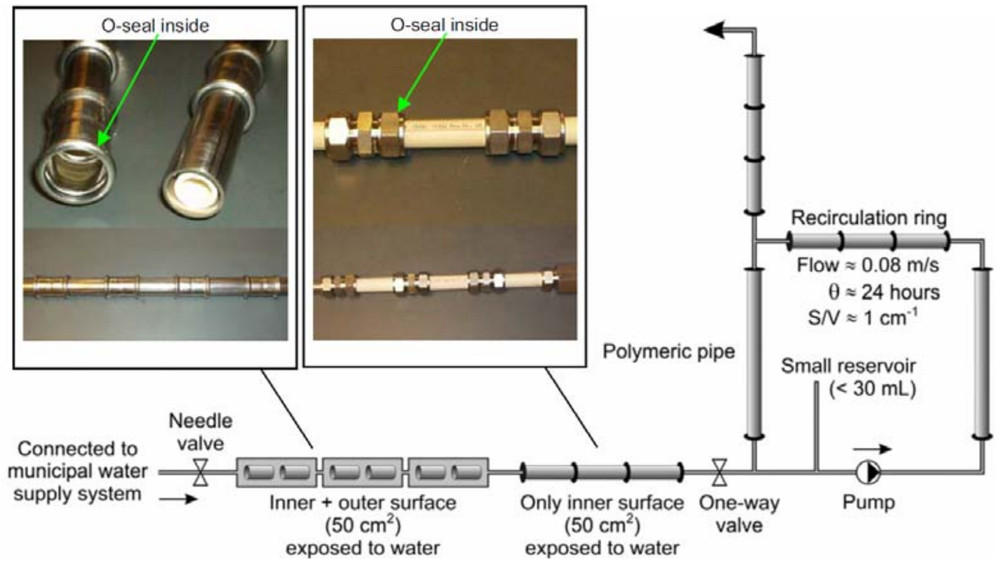

Fig. 8. Continuous flow model system for investigating biofilm formation on polymers [13,14].

The current metal release test rig at Regnemark water work runs with the water quality present, which is known to be quite aggressive in terms of corrosion and metal release. The tests can therefore be used as a worst case scenario, but data can only be generated on the water produced at this water works. In order to study different water types either a mobile test rig must be designed and moved around the country or simpler and less advanced test rigs could be installed in different areas of the country representing different and possibly varying water types. Relevant adaptations of the biomass production potential tests could be included.

Discussion

So far, Denmark has been fortunate in having high quality ground water and a huge effort has been made to ensure that the water reaching the consumers is natural, clean and safe. Generally, a minimum of chemical disinfection is preferred and good housekeeping is the basic strategy. Polymers are increasingly being used for both distribution and domestic installations. This induces an increased AOC in the water, which could give microbial growth in the domestic installations with long contact time and high surface to volume ratio. The impact of this should be evaluated to improve approval criteria for specific polymer materials and products.

The current evaluation of material integrity is linked to geographical areas of typical water types. To secure the integrity of existing and new installations, issues of corrosion and possible need for disinfection must be elucidated under conditions of changed water qualities. The future water resources are likely to include less ground water and more treated water types. The tests for CPDW approval both related to metal release and to release of organic compounds facilitating growth are a major improvement, which can sort out the most critical products from the market. Approval tests for new products are fine to test product and material properties under controlled standardized conditions, which is necessary to achieve reproducible and generally applicable results. However, if the preconditions are changed because the water quality is changed by the water supply, the water supply must have the responsibility to test or estimate the effects of such changes.

These factors introduce the need for both better test facilities and a mobile test facility supplying the option of monitoring effects of water quality variations on corrosion properties, metal release, biofilm growth, MIC, and also to test performance of specific components or water treatments under varying conditions. The combination of off-line analytical techniques and on-line techniques should be favoured to add flexibility and improve the options for future drinking water control.

The test facilities must also include evaluation of old existing construction products, of which especially the large amounts of hot dip galvanised steel systems in apartment buildings are a concern. New installations are designed in stainless steel or polymers, which are general shown to be corrosion resistant and give acceptable microbiological quality, provided stagnation and long residence times are avoided.

It is not trivial to centrally supply safe and natural water with a low level of treatment, but the intention is still there, even with the new challenge of less ground water availability. In recent years commercial interest to provide clean water directly to consumers has increased, and the attitude in the public towards application of individual and local water treatments may be changing. The regulation is strict on approvals for components and commercial products, but the future could include a larger amount of individual solutions, new water qualities and local vs. central water treatments complicating the central recommendations on safe material selection.

Conclusion

To secure the integrity of existing and coming new installations issues of corrosion, metal release, aftergrowth potential and disinfection options must be elucidated under conditions of changed water qualities.

The ideal test facility includes the options for

- testing many – and different – construction materials
- testing real construction products
- testing old, previously exposed materials
- simulating real conditions: stagnant, flow, combinations
- testing different water types – locally at works or domestic installations
- testing with standardized water type
- adding chemicals – e.g. disinfectants

- applying alternative disinfection methods to chlorine based
- testing of water-in-pipes
- testing products-in-water, e.g. o-rings or large gaskets
- large series of tests
- on-line data logging in combination with off-line analysis
- mobility of test rig

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