DRINKING WATER, MATERIALS AND THEIR INTERACTIONS – SITUATION IN FINLAND

Tuija Kaunisto
Satakunta University of Applied Sciences
WANDER Nordic Water and Materials Institute
Sinkokatu 11, FI-26100 Rauma, Finland

1 INTRODUCTION

Factors affecting the quality of drinking water include source of raw water, water treatment processes, materials, stagnation times, and microbiological activity throughout the whole chain of the water distribution. Materials and drinking water are in complex interaction which may lead to leaching of substances from materials and formation of biofilms on surfaces, resulting in poor water quality, or corrosion failures decreasing the service life of the components.

The field of waterworks in Finland is fragmented. The number of water works, providing drinking water for > 50 consumers, is approximately 1900. There are 153 large waterworks providing water >1000 m^3/d or for >5000 consumers. Thus the number of small or middle size water works (10-1000 m^3/d) is high.

Approximately 35 % of distributed drinking water is produced of surface water and 65 % of ground water. From the ground water the amount of artificial (synthetic) groundwater is 19 %. Most of the small water works use ground water as such or after filtering.

2 QUALITY OF DRINKING WATER

2.1 Regulation

The Finnish Ministry of Social Affairs and Health has given the decree concerning the requirements and recommendations for the quality of drinking water [1]. The decree is based on the EU's Drinking Water Directive. The Finnish decree has tighter recommendation for limit values for chloride and sulphate than the Drinking Water Directive, in order to prevent corrosiveness of water, but not for pH value. With respect to alkalinity and hardness there is no guide or limit values in the decree.

The limit values for copper, lead and nickel apply to water samples taken from a tap so that they are representative of a weekly average value ingested by the consumer. The sampling method has not been harmonized so far in the EU. In some member states the random day time sampling method is used, and in other the samples are taken after a fixed stagnation period. In Finland the water samples are taken from fully flushed cold water. The influence of the water installation in the buildings is not shown in the measured parameters and consequent statistics.

2.2 Aggressivity of water

Drinking water distributed in Finland by the waterworks is of high hygienic quality, but can be aggressive to materials. Typical for Finnish drinking water is low alkalinity (median 0.9 mmol/l) and low hardness (median 0.6 mmol/l) [2, 3].

According to the recommendation to minimize corrosion, given for waterworks, the pH value should be >7.5, alkalinity (HCO_3^-) >0.6 mmol/l and hardness (calcium) >10 mg/l [4]. However, this recommendation is not binding. Another recommendation for good technical quality of water has been defined, based on literary: pH 7.5-8.0, the bicarbonate content >60 mg/l (alkalinity >1mmol/l), hardness (calcium) >20 mg/l, free carbon dioxide <15 mg/l, chloride <100 mg/l and sulphate <100 mg/l [5].

Drinking water produced of groundwater in Finland is usually acidic and soft and has low alkalinity, and if delivered without treatment, the quality of the water may differ substantially from that recommended (Figure 1).

Water works using ground water should treat the water to lower aggressiveness which also would help to achieve longer lifetime for metallic materials and lower maintenance costs. For example lime alkalisation is a simple method to raise the pH and alkalinity.

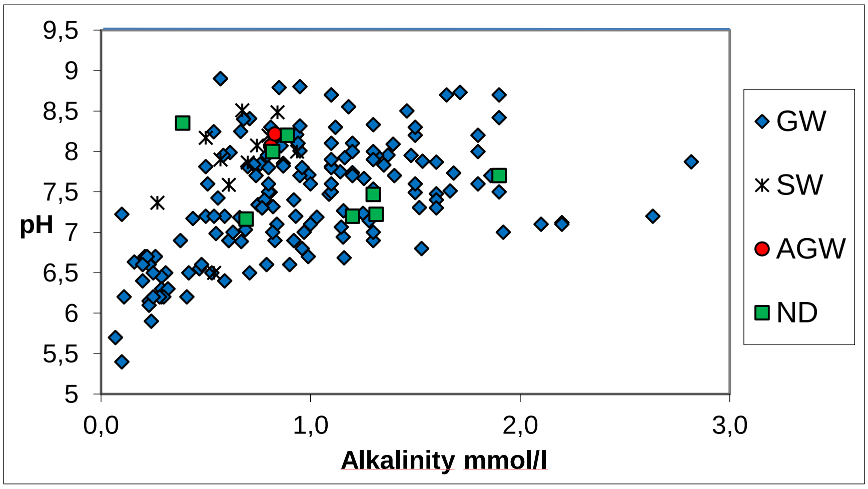

Figure 1. Relation of pH and alkalinity in Finnish drinking water produced of different type of raw water. GW=ground water, SW=surface water, AGW=artificial ground water, ND=not determined, no information from waterworks on source of used raw water. [2]

2.3 Microbiological quality

Even though drinking water is cleaned and disinfected in waterworks, the network always contains microbes which fairly rapidly form a biofilm on all material surfaces which are in contact with drinking water. Organic carbon is nutrient for microbes. The total organic carbon (TOC) concentrations are always relatively high in Finnish waters, with the mean of 1.9 mg/l. Usually only a small part of total organic carbon is easily utilized by microbes. The microbial growth in drinking water is limited by assimilable (available) organic carbon (AOC) or biodegradable organic carbon (BDOC). The AOC concentrations in Finnish drinking waters are in general high, which means that the growth potential of microbes is also high [6].

Phosphorus is also an essential nutrient for microbes. Microbially available phosphorus (MAP) describes that part of phosphorus, which is easily available for microbes. In most Finnish drinking waters, microbial growth is limited by phosphorus, and MAP correlates with the growth potential of microbes. Very low amounts of phosphorus have been shown to greatly increase the microbial growth. The amount of MAP and microbial growth potential is highest in less treated drinking waters produced from ground water and lowest in drinking waters produced from surface waters with efficient purification treatments. Similar results have been reported from Japan and Latvia. [7, 8]

3 MATERIALS USED IN THE DRINKING WATER NETWORK

There are no regulation or recommendations, given by the authorities, for materials and products used in waterworks or in the distribution network.

The main materials installed in distribution networks are polyethylene (HDPE, MDPE), cement mortar coated ductile iron, and polyvinylchloride (PVC), in addition to stainless steel. Some pipes of steel, grey cast iron and asbestos cement are still in use. [5]

The largest number of leakage incidents in drinking water distribution network has reported for grey cast iron pipes, following the group “others” (mostly steel), ductile iron and HDPE. Installation faults and mechanical damage were estimated as the most common causes of damage in HDPE and PVC pipes. In particular, pipes of medium density polyethylene (MDPE) had a high rate of installation faults. Mechanical loading seemed to be the main cause of damage in ductile iron, asbestos cement and grey cast iron pipes. Joints have a more substantial impact on the rate of damage in plastic pipes than in cast iron pipes. [5]

There have been occasional cases of microbiological problems after installation of new plastic pipes, mostly PEH, in the distribution line in waterworks, using ground water or artificial groundwater. Increase in the heterotrophic plate count as well as unpleasant taste and odour were noticed in the normal control after installation, and the pipes have not been able to take into use without further treatments. In some cases the microbiological quality of water remained good after an effective flushing and disinfection treatment, but in some cases these procedures have not helped and the pipes have been replaced with new. Pipe materials may possibly have had influence on the events, but this was not studied. It was concluded, that in most cases the pipes were probably contaminated in the storage or during the installation, and the normal disinfection procedure after installation has not been effective enough. Especially harmful was the stagnation of water in pipes for weeks or months before the pipeline had been taken in use. [9]

4 WATER INSTALLATIONS INSIDE BUILDINGS

According the National Building Code D1 [10] the water supply installation shall be constructed of such materials that substances hazardous to health cannot be released into the water. The materials of the water supply installations shall fit in use, and their quality shall be tested and inspected. The regulations don't give specification for accepted materials or products, but voluntary type approval decrees have been given for pipes, fittings, taps and valves.

Hot and cold water pipes installed inside buildings are copper, cross-linked polyethylene (PEX) or multilayer pipes, in which the material in contact with drinking water is either PEX or PE-RT (polyethylene of raised temperature resistance), and also stainless steel pipes. Brass is common fitting and valve material, and the alloys used in contact with water should be dezincification resistant and pass the leaching test for lead and cadmium. Brass fittings should also pass the test for stress corrosion cracking.

Galvanized steel was a common material in cold water pipes, but has not been installed since the 1970's because of its poor corrosion resistance in Finnish water. Some galvanized steel pipes are still in use.

Old water pipes are starting to require renovation. Different types of trenchless techniques and coating methods, used for a long time in the water works, have become more and more common also in the building networks. For example old drinking water pipes inside buildings have been coated with epoxy. Since the safety and long-term durability of them are not known completely, the building authorities may require periodical water sampling to control leaching of harmful chemicals into drinking water.

4.1 Failures in cold and hot water plumbing

The costs of leak damages covered by the insurance (both in households and enterprises) have been increasing, since about 80 million Euros was paid out in compensation in 2000 and by the year 2012 the amount of money was almost 157 million Euros. This sum does not represent all the financial losses because not all incidents are compensated owing to different insurance terms. Most cases of plumbing leaks were in sewer (21 %) and cold water pipes (18 %). In the equipment leaks were mostly in dishwashers (12 %) and sanitary tapware (10 %). The main causes of the leaks were mechanical damage and corrosion. [11]

In planning of the water systems, the quality of the local water should be taken into account, and new solutions for leak detection should be introduced. Too many of the damages in drinking water plumbing occur due to mistakes in installation and procedures before use. In spite of this, installation of water pipes is not subject to licence in Finland.

4.2 Copper pipes and brass fittings

Main causes of leaks in copper pipes are pitting corrosion and erosion-corrosion.

Pitting corrosion occurs in household water supply systems occasionally, and the main reason cannot always be found. Water quality is important factor and especially the variation in pH has been found to have a detrimental effect. Also design, installation, commissioning and maintenance of the water installation and variation of water use affect the durability. Corrosion failures occur in all kind of buildings, but most problematic are large public buildings like schools. Irregular use and long stagnation periods of water are typical for these.

Silicates have been reported to promote pitting corrosion in copper pipes in specific waters in Scandinavia. Dissolved silica contents of 10-20 mg/l seem to be critical for the formation of heterogeneous silica film inside copper pipes, leading to pitting. However, the chemical quality of water, like pH and hardness, is believed to also influence, but the mechanisms are not known.

Erosion-corrosion of copper pipes is mostly caused by too effective pumps, resulting in high flow rates, or poor joints and poorly installed branch pipes, influencing turbulence.

Dezincification of brasses was common in drinking water installations previously, but in the 1980’s it was regulated, that the brass components in water installations inside the buildings has to be manufactured from dezincification resistant brass.

Stress corrosion cracking of brass components has been main cause of leakages in brass fittings, although the Finnish type approval rules of brass fittings in potable water systems demand testing for stress corrosion cracking resistance.

4.3 Failures of multilayer pipes

In multilayer pipes, between the inside and outside polymer layers (PEX or PE-RT) there is a metal layer of aluminium. In one case the multilayer pipes for hot water inside buildings have been damaged one year after installation, resulting in leakages. In some pipes the outer polymer layer has been clearly stretched and detached from the metal surface, while in another pipes there were white precipitates between the metal and the outer polymer layer, resulting also detachment of the layers. Too high water temperature may cause this kind of damages, but in this case the temperatures were at normal level.

The white precipitate was aluminium oxide/hydroxide from the corroded metal layer. The inner polymer layer of the pipes was heavily damaged in several places. The investigations revealed that contents of stabilizers, essential for long-term durability and thermal resistance, were low, thus shortening the lifetime of pipes at high temperatures. Polymer materials did not include enough metal deactivators which are needed to prevent degradation caused by metal ions in water.

4.4 Taste and odour problems

There have been occasional cases in different parts of Finland, where some PEX pipes, installed in new or renovated buildings, have caused non-acceptable taste and odour to cold and hot water. Consumers have noticed this especially in the morning when water has been stagnated overnight, but in some cases bad odour has remained even after long flushing of water.

Chemicals like MTBE, ETBE, TAME and TBA were found in the water samples taken from the private houses. The concentrations have been up to some hundreds of micrograms per litre. Variations in concentrations of chemicals between nearby flats in the same building have been noticed. In some cases odour problems existed although the concentrations of identified chemicals have been low, probably caused by some unidentified chemicals. Currently, there is not enough research information on all potential dissolving substances to estimate their health effects. [12]

According to the Ministry of the Environment the PEX pipes do not pose health risk, although influences of all chemicals leached in water are not known. Likely there have been some problems in the production process, which now have been improved as well as the quality control system to ensure the quality of the pipes.

5 RESEARCHES ON INTERACTION BETWEEN DRINKING WATER AND MATERIALS

5.1 Pilot research

Formation of biofilms on the surface of different pipe materials as well as leaching of substances from materials has been studied in a pilot research carried out 2007, coordinated by WANDER, and in cooperation with the National Public Health Institute of Finland and Savonia University of Applied Sciences. [13]

5.1.1 Materials and methods

The materials tested were cement mortar coated ductile iron (EN 545) and polyethylene of high density (PEH, EN 12201-2) used in water mains, and copper (EN 1057), brass (CuZn36As, EN 12449) and PEX (EN ISO 15875-1 and -2) used in household plumbing. Pipes of 5 m long were installed in the pilot system with flow and stagnation conditions corresponding to the real system. There was flushing for 1 min (PEH, ductile iron) or 5 min (PEX, copper, brass) with flow rate of 0.63 m/s every 4 hours. Between flushing water was stagnated in the pipes.

The water was drinking water produced of bank filtrated lake water with chemical Al-coagulation and chlorination. The quality of the water was following: pH 8, alkalinity 0.7-0.8 mmol HCO_3^-/l, hardness 0.6 mmol/l, TOC 2.5-3.2 mg/l, AOC around 100 µg/l and total Cl <0.1 mg/l.

During the research period of 4 months water samples, after 4 hours stagnation, were taken weekly. Pipe samples for biofilm studies were taken three times, after about 2, 3 and 4 months. Biofilms were removed from the pipe samples filled with water by shaking them with sterile glass beads and flushing them with sterile water. Biofilm samples were analysed by the National Public Health Institute.

5.1.2 Results and discussion

Metals were leaching from the metallic materials, but with acceptable concentrations. Copper release from copper pipes was 200 – 450 µg/l, and about 150 µg/l from brass pipes. Zinc was dissolved from brass components with the concentration of <600 µg/l. Lead release from brass was ≤2.5 µg/l, which was expected as the lead content of the alloy was very low. Nickel concentration was <10 µg/l.

Pipe materials did not have influence on the total microbial count (AODC) in water. Water from copper pipes had clearly much less assimilable organic carbon (AOC) than the incoming water, while other materials did not have influence on the AOC concentration.

Biofilm was forming on all material surfaces, although there were some differences in the volume and community structure in biofilms. ATP concentration in the biofilms of PEH pipe samples increased with time while in other materials concentrations were more stable. Bacterial diversity on biofilms of copper and brass was lower than that on the other materials.

From cement mortar some calcium and probably also sulphur were leached into water, and pH was increased to around 8.7. During the first weeks also hardness was higher (<1.1 mmol/l) than in the incoming water. SEM investigations revealed clearly the porous surface structure of the cement mortar surface after exposure. There were more and larger pores in the test sample when compared to the reference sample. This kind of degradation of cement materials seems to be typical in very soft water which is aggressive to calcium carbonate. It was not possible to find out, during the test period of 4 months, whether the degradation rate would have been decreased or increased with time.

According to the results there were no remarkable differences in the interactions of water with different material types. However, it should be remembered that in this case the drinking water was of good technical quality. Longer research period would have been needed to study the changes in the materials. However, all the materials studied were considered suitable for drinking water installations using water of good quality in Finland.

5.2 Living Lab studies

Short testing of weeks or couple of months doesn’t give real results of materials behaviour during the lifetime of several decades. Long-term research on interactions is usually not possible in laboratory, but with Living Lab concept in a real life setting using a full scale system both water quality and materials can be studied.

5.2.1 Materials and methods

WANDER has performed Living Lab research in the office building Sytytin in Rauma, Finland. About 250 people are working in this building. The water distribution system of the building was designed for full-scale research purposes and had been planned and installed according to current legislation and protocols in Finland. In one part of the building the material of the cold and hot water pipes is copper (EN 1057), and in other part it is cross-linked polyethylene (PEX, EN ISO 15875-2). A short line of cold water was also installed with multilayer pipes (EN ISO 21003). Brass fittings and valves were used in pipe systems. All products were specified by product standards, manufacturers and type approval. [14]

Drinking water was delivered from the municipal waterworks and produced of surface water. The quality of water was following: pH 8.3, alkalinity 0.4-0.6 mmol/l and hardness 1.2-1.6 mmol/l.

There are 11 places in the building where water samples can be taken and pipe samples can be withdrawn and replaced without disturbing the normal life in the building. Water samples were taken without flushing on Monday mornings, when the water has been stagnated during the weekend and in Thursday mornings after stagnation overnight.

The water consumption is of normal office building characteristics with frequent use from Monday to Friday with rush hours falling on mornings, middays and coffee breaks. Warm water circulates continuously, but cold water consumption varies a lot and long stagnation periods can take place.

Substances leaching from pipe materials and water fittings, as well as the microbiological quality of water and formation of biofilms were evaluated during the first year of operation, after the building was finished April 2011. Before withdrawing the pipe sample, they were closed with valves and removed with the water still inside. After then the new pipe samples were installed. Biofilms were removed from pipe samples by shaking for 10 min with sterile glass beads followed by rinsing with sterile water. Biofilms were studied by the National Institute for Health and Welfare (former National Public Health Institute).

The results have been reported in more detail in the article of Water Research [14]. The main conclusions will be presented in this paper.

5.2.2 Results and discussion

Metal leaching

Operational conditions, such as flow conditions and temperature affected the amounts of metals leaching from the metallic pipes and components.

Lead was leaching from the brass components in both cold and hot water systems. This was noticed when the concentrations after the pipe sampling unit were compared to the incoming water. The concentrations were highest (40 µg/l) during the first weeks after the water installations were taken into use, following a decrease after 3-4 weeks. Then there was again an increase in lead concentrations after 3 months of exposure, and finally the concentrations were low again after 8-9 month.

However, the lead concentrations measured should not be compared to the limit value of Drinking Water Directive (10 µg/l), since it applies to weekly average. The procedure was to represent the worst case situation, as water samples were taken directly after stagnation. In normal situation consumers flush the water until it is cold before drinking it. It should also be noticed, that the number of brass components in the studied case was higher than in the usual water installations, due to the pipe sample units with brass valves on both end. Although the brass components to be installed were specified with standards and/or manufacturers to ensure the quality of products, it has been noticed that some of the brass components installed are not the specified products. Thus it is possible, that the quality of these components doesn't correspond to the quality of type approved products.

The main difference on the influence of copper and PEX pipe materials (including the brass components) on the drinking water quality was the concentration of copper. Naturally more copper leached from copper pipes, with the concentration ≤160 µg/l. The concentrations were higher in the stagnated cold water than in the circulating hot water.

Nickel was leached from hot water system, probably form heat exchanger during first two months of use, with the highest concentrations of 99 µg/l.

Microbiological effects

Temperature and flowing conditions of water affected the microbiological quality of water. In cold water with irregular stagnant periods the water contained slightly higher count of total microbes (DAPI) that in hot continuously circulating water.

The cold water quality was getting worse during the weekends. This was noticed from the cultivable microbial biomass (heterotrophic plate count, HPC) values, which increased at every sampling point during the stagnation of weekend.

Assimilable organic carbon (AOC) was found to leach from PEX pipelines, but with minor effects on biomass of the biofilm.

Concentration of AOC was higher in the hot water systems compared to cold water systems, which could be caused by the presence of dead microbes.

Microbially available phosphorus (MAP) concentrations were similar in both PEX and copper pipes for cold water, but in hot water MAP concentration was higher in the PEX pipes. However, this didn't cause increased microbial growth during the first year of operation.

The total organic carbon concentration in the water was quite high, on the average 4.1 mg/l, but, as typical for Finnish drinking water, microbial growth and biofilm formation were limited by low phosphorus concentrations. Pipe materials did not markedly affect the microbial biomass or microbial groups in biofilms. Although there was no difference on the total cell count in biofilms of cold or hot water system, the microbial biomass was higher in cold water biofilms. This means, that biofilms in the circulating hot water system contained higher amount of dead microbes.

6 CONCLUSION AND FUTURE STEPS

The Finnish building regulations are under revision by now. Instead of performance based criteria new regulations should give specified requirements for essential characteristics of construction products. Also the voluntary type approval decrees should be revised, for example by taking in use the EN standards for test methods. However, the advantages and usefulness of EN test method standards should be evaluated.

The type approval decrees don’t give specification for accepted materials for example in taps and valves. Testing for metal leaching (Pb, Cd) is required for brass components, but it is a short-term test in synthetic water with limit values which are quite high and not based on the Drinking Water Directive. The concentration of lead in drinking water, which consumers use, have not been studied systematically, since the water samples for control are taken from flushed water.

The responsibilities concerning materials and products in contact with drinking water are not clear in Finland. There are two ministries involved in this sector. The Ministry of Social Affairs and Health is responsible for the quality and monitoring of drinking water and the Ministry of the Environment for water installations inside buildings. The discussion of this issue has started, and decision is needed before development of national approval system will progress.

Use of common European test methods would be beneficial for the manufacturers, if the products could be accepted in most European countries after one testing, although the limit values may differ. Because of differences in drinking water quality, use of EN test methods does not show the acceptability of product in every European country, especially when the test water is local drinking water. There are significant differences in the chemical and microbiological quality of drinking water in Europe, and thus also in the test water quality, although the local drinking water fulfils the requirements of the Drinking Water Directive. As the consequence of this the same test for the same product might give different results, depending on the test water quality.

Test of microbial growth has not been taken into use in Finnish type approval. All the test methods of enhancement of microbial growth of EN 16421 [15] test whether materials in contact with drinking water promote microbial growth, and organic carbon has been assumed as main nutrient. However, as most Finnish waters are phosphorous-limited, the critical element for microbial growth in this kind of waters is phosphorous, not carbon. It is also known that biofilms will form more or less on all surfaces and within a year organic and metallic materials have similar concentration of microbes. However, the microbial communities may differ in different materials.

In spite of material types in water installations, water should be flushed after stagnation before taking it for drinking or food preparing to ensure both chemical and microbiological quality of water.

The Nordic project **Material and product innovation through knowledge based standardization in drinking water sector** (MaiD) will hopefully help the national revision work, if recommendations for key components included in acceptance schemes would be given as a result of the project.

References

1. Finnish decree on drinking water, Regulation 461/2000. Decree Relating to the Quality and Monitoring of Water Intended for Human Consumption. Ministry of Social Affairs and Health, 2000. (In Finnish)
2. Ahonen, M.H., Kaunisto, T., Mäkinen, R., Hatakka, T., Vesterbacka, P., Zacheus, O. & Keinänen-Toivola, M.M. Quality of Finnish Drinking Water from Raw Water to Consumers Tap in Years 1999-2007. Finnish Institute of Drinking Water/Prizztech Ltd, Finland, 2008. 147 pp. (In Finnish)
3. Mäkinen, R. (Ed.) Drinking Water Quality and Network Materials in Finland. Summary Report. Publications of Finnish Institute of Drinking Water 5, Finnish Institute of Drinking Water/Prizztech Ltd, Finland, 2008. 83 pp.
4. An application directive to the Finnish decree on drinking water. Finnish Water and Waste Water Works Association and Association of Finnish Local and Regional Authorities. Finland, 2001. (In Finnish)
5. Kekki T.K., Kaunisto T., Keinänen-Toivola M.M. & Luntamo M. Failures and service life of materials in drinking water mains and household plumbing in Finland. Publications of Finnish Institute of Drinking Water 3, Finnish Institute of Drinking Water/Prizztech Ltd., Finland, 2008. 186 pp. (in Finnish).
6. Miettinen IT, Vartiainen T and Martikainen PJ. Determination of assimilable organic carbon in humus-rich drinking water. Water Research 33(10),2277-2282, 1999.
7. Miettinen I.T., Vartiainen T. & Martikainen P.J. Phosphorus and bacterial growth in drinking water. Applied and Environmental Microbiology 63(18), 3242-3245, 1997.
8. Lehtola, M.J., Miettinen, I.T., Vartiainen, T. Martikainen, P.J. Canges in content of microbially available phosphorus, assimilable organic carbon and microbial growth potential during drinking water treatment processes. Water Research 36: 3681-3690, 2004.

9. Herrala, M. Microbiological challenges of new distribution pipes for drinking water. Thesis for Bachelor of Science, University of Eastern Finland, 2011. (In Finnish)
10. The National Building Code of Finland D1. Water supply and drainage installations for buildings. Regulations and guidelines. Ministry of the Environment, 2007. (In Finnish)
11. Report of leak damages 2012-2013. Federation of Finnish Financial Services. (In Finnish)
12. Komulainen, Hannu. Taste and odour problems of drinking water pipes of plastics. http://fi.opasnet.org/fi/Muovisten_vesijohtoputkien_maku-_ja_hajuhaitat (Referred 22.04.2015) (In Finnish)
13. Keinänen-Toivola, M.M., Lehtola, M.J., Mäkinen, R., Hokajärvi, A.-M., Kaunisto, T., Carpén, L., Pohjanne, P., Pyykkö, M., Kuhmonen T. & Miettinen, I.T. Leaching of Compounds and Formation of Biofilms on Distribution System Pipe Materials in Finland. (Poster presentation) International Water Association (IWA), World Water Congress in Vienna 8.9-10.9.2008.
14. Inkinen J., Kaunisto T., Pursiainen A., Miettinen I.T., Kusnetsov J., Riihinen K., & Keinänen-Toivola M.M. Drinking water quality and formation of biofilms in an office building during its first year of operation, a full scale study. Water Research 49: 83-91, 2014.
15. EN 16421 (2014) Influence of materials on water for human consumption. Enhancement of microbial growth (EMG).