DRINKING WATER QUALITY ON CUSTOMER'S TAP – CORRELATION WITH MATERIALS USED IN DOMESTIC DISTRIBUTION SYSTEMS AND RECOMMENDATIONS FOR QUALITY IMPROVEMENT

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Abstract

Drinking water produced in water plants almost invariably fulfils the water quality requirements set in European Union Drinking Water Directive (Council Directive 98/83/EC, 1998). However, the DWD requires that water quality should also meet the requirements at the consumer's tap.
When drinking water is distributed through pipelines, biofilms will grow on the inner surface of the pipes and soft deposits (organic and inorganic matter) and several metals will accumulate to the pipelines. Corrosion of household plumbing systems is an important source of trace metals found in tap waters. Significant levels of trace metals could be detected after stagnation of the water in distribution system, especially during night – time.
In order to get an overview of the overall current contamination levels of drinking water at the point of consumption were collected and analysed more than 600 samples from cold line-pipe with three different sampling procedures (first draw, fully flushed and randome daytime). A monitoring plan was developed and the content of metals was analyzed from drinking water samples collected directly from consumers and from the municipal distribution network. In the study were correlated data regarding metals concentration in customer's tap water and materials used in domestic distribution systems in order to investigate influence of materials to the tap water quality.

Keywords: drinking water, distribution system, materials, PVC, metals

Introduction

The purpose of every water utility is to provide consumers with drinking water that presents no risk to public health. Safe drinking water is generally obtained by complying with specific water quality standards such as European Union Drinking Water Directive (Council Directive 98/83/EC, 1998).
Corrosion can affect public health, public acceptance of a water supply and the cost of providing safe drinking water. The release of corrosion by-products of household plumbing systems can be a significant source of trace metals found in tap waters [1]. Pollution with metals may originate mainly from old and poor quality distribution networks and piping systems.
When drinking water is distributed through pipelines, bio-films will grow on the inner surface of the pipes and soft deposits (organic and inorganic matter) and several metals will accumulate to the pipelines [2]. Discoloration of drinking water is one of the main reasons customers complain to their water company.

An elevated concentration of iron or increased turbidity, affect taste, odor and color in drinking water. Unlined iron pipes in drinking water distribution networks develop extensive internal corrosion scales as the time of use increases. These corrosion scale deposits reduce the hydraulic capacity of the pipes and more energy is required to deliver water at a desire flow rate [3].
The heaviest corrosion was observed mainly in steel and cast iron pipes [4]. Corrosion of cast iron and iron products is ofen seen as the main source for discolouration of drinking water, iron higher content and may can also induce a chemical decay of the residual chlorine [3,5].
High contents of Cu can be released in drinking water as an effect of using the copper or copper alloys pipes for cold-water domestic installation. In copper pipes, the concentration of copper in water incresed with increasing stagnation time [6, 7]. Merkel et al found that during stagnation, the concentration of copper reached its maximum after 10 hours, and then it started to decline. Water stagnation for more than 4 hours significantly increased the cooper concentration in water [8, 9]. In Romanian legislation, the maximum admissible value for Cu in drinking water (100 µg/L) is lower than the limit imposed by EU Drinking Water Directive (2,000 µg/L).
The major source of lead in drinking water was identified to be plumbing materials. Lead pipes, lead – based solder, brass fittings and plumbing fixtures such as pipe's jointing faucets are known to be dominant lead sources in public water supply systems [10].
Lead pipes were replaced with other types of pipes such as polymer materials like polyvinyl chloride (PVC), polyethylene (PE) and polypropylene (PP). Plastic pipes currently make up about 54% of all pipes installed worldwide. PVC makes up 62% of this demand and PE in its various forms about 33.5% [11].
PVC polymer is mixed with a number of additives including stabilizers in order to provide the range of properties needed in the final products. Stabilizers are often composed of salts of metals like lead and cadmium [12]. Unlike PVC, other plastics including PE and PP do not require metallic heat stabilizers. In addition, galvanized iron pipe can release significant amounts of lead into drinking water, as the zinc coating contains about 1% lead impurities.
Nickel can be leached from the internal surface of some components of domestic installations such as: Cr/Ni plated devices, alloys containing nickel [13].
In the process for drinking water production, usually, the raw water is treated with aluminium sulphate as coagulation agent, for this reason is important to control aluminium. The role of Aluminium in Alzheimer illness is not well known but is certainty known that this metal has a toxic effect on the nervous system [14]. Aluminum has been shown to play a causal role in dialysis encephalopathy and epidemiological studies suggest a possible link between exposure to this metal and a higher prevalence of AD [15]. This association is dependent on the duration of Al exposure and only becomes significant if an individual has resided in an area with high Al in drinking water (>100 µg/L) for several years.
Tap water from the municipal supply system is the source of drinking water for majority of consumers in Romania. The main sources of drinking water in Romania include rivers (about 60%), drillings and much less, lakes.
According to Romanian legislation, the last segments checked by the Water Companies are branch pipe and water meter. Less than 0.1% of domestic

network of customer is included in monitoring plan of drinking water; usually, the tap water is controlled only at customer request or complaint.
The aim of the study was to identify issues that may affect public health and the risk prevalence of relevant metals in in-building installation systems, in three important municipalities from Romania. Thus, it is possible to take measures to increase security of water systems, replacement of the pipelines at risk of metal corrosion, improve drinking water quality and protect human health against adverse effects caused by contamination of drinking water.
In order to get an overview of the overall current contamination levels of drinking water at the point of consumption were collected and analysed more than 600 samples from cold line-pipe with three different sampling procedures (first draw, fully flushed and randome daytime). A monitoring plan was developed and the content of metals was analyzed from drinking water samples collected directly from consumers and from the municipal distribution network.

Experimental part

A large distribution system delivering drinking water to about 1.7 million citizens, supplied by three water treatment plants and two different surface water sources was investigated. Arges River, raw water source for Crivina and Rosu Water Plants, is affected by anthropogenic pollution; the river collects wastewater discharges from industrial areas located downstream near Curtea de Arges and Pitesti cities. In case of accidental pollution of both rivers uses as raw water (Arges and Dambovita Rivers), the operator, APA NOVA Bucharest, has in place necessary means to eliminate the pollutants.
Second city selected was Timisoara. The most important raw water source in collected from Bega River, which is clogged and the water is cloudy for most of the time. The water and sewerage operator, which provide drinking water in Timisoara city is AQUATIM Company.
The last city selected was Targu Mures. As only source of raw water is used Mures River. The river collects discharges from several locations upstream of Tg. Mures, most important being Reghin and Toplita cities. In Tg. Mures municipality, AQUASERV Company is the producer and distributor of drinking water.
In order to obtain a large database, the samples were collected from customer's cold line-pipe with three different sampling techniques: first draw sampling (from kitchen); fully flushed sampling procedure after flushing five minutes same tap; random daytime procedure (within office hour, without previous flushing of the tap).
Each type of sampling technique provides different informations about influence of materials used in both distribution systems (municipal and domestic) to the tap water quality. Thus, the results obtained with fully flushed procedure indicates the influence of municipal distribution system to the tap water supplied by the Operators. The first draw results shows in principal the influence of materials used in domestic distribution system. Random daytime (RDT) sampling was identified as the best approaches for estimating exposure and detecting homes with elevated lead concentration in tap water.

Table 1. General characteristics of the utilities under study

	BUCHAREST			**TIMISOARA**			**TARGU MURES**
Population served	1725,000 inhabitants (December 20 09), 81% from Bucharest population			330,000 inhabitants (December 2010), 99% from Timisoara population			143,000 inhabitants (December 2010), 95,25% from Tg. Mures population
Source of raw water	*Arges River*		Dambovita River	Bega River	Groundwater (63 drilling points)		Mures River
Water Plants	*Crivina*	*Rosu*	Arcuda	Bega	Urseni	Ronat	Tg. Mures
Supplied flow rate (m^3/day)	259,200	400,000	610,000	69,676	26,131	1,311	46,000
Treatment processes	*pre-ozonation*→coagulation (aluminum sulphates) → flocculation → decantation → inter-ozonation**→ sand filtration → disinfection with chlorine gas* *, ** only in Crivina Water Plant			*Coagulation (aluminum sulphates, sodium aluminates, aluminum sulphates hydrolyzed) → flocculation → decantation → sand filtration → disinfection with chlorine gas*			*Pre-oxidation with $KMnO_4$ → pre-decantation → coagulation (aluminum poly hydroxyl chloride) → flocculation → decantation → sand filtration → ozone treatment → adsorption on granular active carbon → disinfection with chlorine gas*

In the study were collected samples from producer via distribution system to consumer's tap, from different points such as:

- Water Plants - drinking water produced by the Water and Sewerage Operators;
- monitoring points of the Operators, situated in different locations in the municipalities, such as elementary and high schools, kindergartens, markets, fountains, public institutions, pumping stations (fully flushed samples);
- selected customers of the Operators with the residence in different districts of the municipalities (first draw and fully flushed samples);
- medical centres, pharmacies, schools, private companies, public institutions, food markets, fast foods, restaurants situated in old buildings from the centre of the cities –(random daytime samples).

In table 2 are presented data regarding number of samples collected in the study for each municipality and also the date when the samples were collected.

Table 2. Number of samples collected in the study

Municipality	Samples									
	Water Plant		Operator Monitoring points		Customer points					
					First Draw		Fully Flushed		Random Daytime	
	No	Date	No	Date	No	Date	No	Date	No	Date
Bucharest	3	22.06.09	23	23.06.09	71	22-24.06.09	71	22-24.06.09	-	-
Timisoara	3	16.02.10	15	16 - 18.02.10	30	17.02.10	30	17.02.10	-	-
	3	17.02.10								
	3	18.02.10								
	3	23.06.10	15	23 – 24.06.10	30	24.06.10	30	24.06.10	32	24.06.10
	3	24.06.10								
Tg. Mures	4	16 - 18.02.11	30	16.02.11	18	16.02.11	18	16.02.11	-	-
			30	17.02.11	17	17.02.11	17	17.02.11		
	1	30.06.11	30	30.06.11	17	31.06.11	17	31.06.11	45	30.06.11

The parameters Al, As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, Se, Sb and Zn were analysed using inductively coupled plasma atomic emission spectroscopy ICP-EOS technique. The samples were digested with suprapure nitric acid (5 mL for each sample) and concentrated from 150 mL (sample's volume) to 25 mL.

Results and discussions

In Bucharest, a high percent of first draw samples exceeded the iron concentration limit (table 3). Materials used for pipes and fittings in the domestic distribution system in this points are either metallic (Cu, Pb, cast iron) or a combination of plastic and metallic pipes. In addition, the pipes and fittings of APA NOVA Bucharest distribution system are either cast iron, steel or PEHD (high density polyethylene), that's why the effect observed may be a combination of both distribution systems. As was mentioned above [3, 5], corrosion process in cast iron is the main source for discolouration of drinking water and iron higher content.

Table 3. Bucharest, source of metals in first draw samples

Point	Values higher than limits	Household -primary material	Municipal distribution system - primary material	Branch pipe
0	***1***	***2***	***3***	***4***
C1	Cu, Ni	PexAl, Cu	Cast iron	Pb
C2	Fe	PVC, cast iron	Cast iron	Pb
C4	Cu, Ni	PVC, Cu	Cast iron	Pb
C6	Fe	Cast iron, plastic pipe	PEHD	Pb
C7	Fe	Cast iron	Cast iron	Cast iron
C8	Fe	Cast iron	Steel	Pb
C11	Fe	PVC	Steel	Steel
C12	Fe	PVC, cast iron	PEHD	PEHD
C16	Ni	Metallic pipes	Cast iron	Cast iron
C17	Cu	Cu, PE	Cast iron	Cast iron

0	***1***	***2***	***3***	***4***
C18	Fe, Pb	Pb	Cast iron	Pb
C19	Fe, Pb	Pb	Cast iron	Pb
C21	Fe	PVC	Asbestos-cement, Cast iron	Steel
C23	Al, Fe	PVC	Asbestos-cement, Cast iron	Cast iron
C24	Ni	PVC	Cast iron	Cast iron
C25	Al, Fe, Ni	PVC	Asbestos-cement, Cast iron	Cast iron
C27	Ni	Cast iron	Cast iron	PEHD
C31	Cu, Pb	PVC, Cu	Cast iron, Pb	Pb
C34	Fe	Metallic pipes	PEHD	PEHD
C35	Fe	Cu, Pb, galvanized pipe	Cast iron	Cast iron
C37	Ni	PVC	Cast iron	Cast iron
C38	Pb	Pb	PEHD	PEHD
C40	Fe, Ni	Metallic pipes	Cast iron	Cast iron
C42	Fe, Cu	Cu	Cast iron	Cast iron
C43	Fe	Metallic pipes, PExAl	Cast iron	Cast iron
C47	Fe	PVC	Cast iron	Cast iron
C49	Fe, Ni	Plastic	Cast iron	Pb
C50	Fe, Mn, Ni, Zn	Metallic pipes	PEHD	PEHD, Cast iron
C51	Fe	PExAl, Pb	Cast iron	Cast iron
C54	Fe	Cast iron, Pb	Steel	Steel
C58	Al, Fe	PVC, metallic pipes	PEHD	PEHD
C59	Cu, Fe	Cu, cast iron	PEHD	PEHD
C61	Cu	Cu	PEHD	PEHD
C63	Fe	Metallic pipes	PEHD	PEHD

Lead contents above the limit are reported in apartments were either the Pb pipes are inside the building or the Pb branch pipes are used to connect municipal distribution network with domestic system.

Source of high levels of copper in first draw samples is only the Cu pipes used for cold water supply in household. The customers have installed central heating in their apartments and hot water circuit was making with copper pipes.

In addition, they have replaced the old cold water pipes with copper pipes and can be observed the results, more obvious in Timisoara (table 4) and Targu Mures (table 5).

In Timisoara (table 4) were reported higher values than the limits in first draw samples for Cu, Fe, Ni and Pb.

Table 4. Timisoara, source of metals in first draw samples

Point	Values higher than limits		Household - primary material	Municipal distribution system - primary material	Branch pipe
	Winter	Summer			
0	***1***	***2***	***3***	***4***	***5***
C5	Cu	Cu, Ni	Cu	Cast iron	PE
C6	Cu, Pb	Cu, Pb	Cu	Cast iron	Steel
C9	Cu	Cu	Cu	PE	PE
C12	-	Cu	Cu	PE	PE
C13	Cu, Pb	Cu	Cu	Cast iron	Pb
C18	Fe	Fe	Steel	Cast iron, PE	PE

0	***1***	***2***	***3***	***4***	***5***
C19	-	Pb	PVC	PE	PE
C20	Pb	Cu, Pb	Cu	Steel	Pb
C21	Cu	-	Steel	PE	PE
C22	Cu, Pb	-	Cu	PVC	Steel
C25	Ni	Ni	Steel	Cast iron	Steel
C27	Cu, Pb	Cu	Steel	PVC	Steel
C29	Fe	-	Steel	PE	PE
C30	Cu	Cu	Cu	Steel	Steel
C31	Al, Fe	Fe	Steel	Cast iron	Steel
C33	Fe	Fe	Steel	Cast iron	Steel
C35	Cu, Fe	Cu, Fe	Cu	Cast iron	Steel

Table 5. Targu Mures, source of metals in first draw samples

Point	Values higher than limits		Household - primary material	Municipal distribution system - primary material	Branch pipe
	Winter (2 days)*	Summer			
C1	Fe /2	Fe, Pb	PP	PE	PE
C2	Fe /1	-	Cu	Asbestos-cement	Steel
C3	Cu, Ni /1	-	Cu	Steel	Steel
C4	Fe /2	Al, Fe	Cu	Steel	Steel
C7	Cu /2	Cu, Fe	Cu	Steel	Steel
C8	Ni /2	Cu	PE + Steel	PE	PE
C10	Cu /1	-	Cu	Steel	Steel
C12	Fe /2	-	Steel	PE	PE
C16	Fe /2	-	Steel	PE	PE
C18	-	Fe	Steel	PE	PE

*the monitoring programme includes two consecutive days of sampling.

The sources for lead contents higher than the limit are either branch pipes or PVC pipes. The stabilizers used for PVC production are often composed of salts of metals like lead and cadmium [12], in order to provide properties needed in the final product. High content of nickel, was observed in same samples (table 3 to 5), which was generated, probably, by cheap taps with poor quality.
As we can see in table 5, source of Fe in first draw samples could we also unprotected steel, used in both distribution systems.

Conclusions

This research activity demonstrates that materials used in water distribution systems are part of the overall treatment process that affect the water quality which consumers drink at their tap. The interaction between water and the infrastructure used for its supply are fundamental in producing safety drinking water. Subtle reactions between water and different materials used for its transport can affect the finale quality delivered to consumers.
The study, developed in the period June 2009 – June 2011, in a project regarding safety of drinking water distribution systems in some municipalities from Romania, demonstrated that materials used in drinking water domestic

installations have a major contribution in the deterioration of water quality supplied by local distribution operators.
In some locations, in first draw samples collected in the morning from kitchen cold taps were detected high quantity of Cu, Fe, Ni and Pb correlated with materials used in internal distribution system (Cu pipes, Pb pipes, PVC pipes, branch pipes, cast iron and unprotected steel pipes, Ni-Cr plated taps). The main causes are the process of water stagnation and the lack of maintenance of the internal distribution materials.
For samples were collected with fully flushed procedure, the quality of drinking water was better, the number of non-compliance samples decreased with 50%.
The customers were advised that, it be not recommended to use the first draw water for cooking and drinking purpose. Recommendations in cases of exceeding the limit values of metals in drinking water were either flushing water for more than five minutes and then use water for household consumption or replacement of pipes and fittings in both, local or domestic distribution systems.

References

[1] Agatenos, C., Okato, P.O., (2008), Studies of corrosin tendency of drinking water in the distribution system at the University of Benin, *Environmentalist,* 28, 379-384;

[2] Lehtola, M.J., Juhna, T., Miettinen, I.T., Vartiainen, T., Martikainen, P.J., (2004), Formation of biofilms in drinking water distribution networks, a case study in two cities in Finland and Latvia, *J. Ind. Microbiol. Biotechnol.,* 31 (11), 489–494;

[3] Sarin, P., Snoeyink, U.L., Bebec, J., Jim, K. K., (2004), Iron release from corroded iron pipes in drinking water distribution systems: effect of dissolved oxygen, *Water Research,* 38, 1259-1269;

[4] Nawrocki, J., Stanislawiak, U.R., Swietlik, J., Olejnik, A., Svoka, M.J., (2010), Corrosion in a distribution system: Steady water and its composition, *Water Research,* 44, 1863-1872;

[5] Lehtola, M.J., Nissinen, T.K., Miettinen, I.T., Martikainen, P.J., Vartiainen, T., (2004), Removal of soft deposits from the distribution system improves the drinking water Quality, *Water Research,* 38, 601-610.

[6] Lytle, D.A., Schock, M.R., (2000), Impact of stagnation time on metal dissolution from plumbing materials in drinking water, *J. Water Supply Res. Technol. Aqua*., 49, 243–257.

[7] Merkel, T.H., Grob, H.-J., Werner, W., Dahlke, T., Reicherter, S., Beuchle, G., Eberle, S.H., (2002), Copper corrosion by-products release in long-term stagnation experiments, *Water Research*, 36, 1547–1555.

[8] Lehtola, M.J., Miettinen, I.T., Hirvonen, A., Vartiainen, T., Martikainen, P.J., (2007), Estimates of microbialquality and concentration of copper in distribute drinking water and highly dependent on sampling strategy, *International Journal of Hygiene and Environmental Health*, **210**, 725-732.

[9] Lytle, D.A., Nadagouda, M.N., (2010), A comprehensive investigation of copper pitting corrosion in drinking water distribution system, *Corrosion Science,* 52, 1927-1938.

[10] Lasheen, M.R., Sharaby, C.M., Kinoby, N.G.El., Elsherif, I.Y., Wakeel, S.T.El., (2008), Factors influencing lead and iron release from some Egyptian drinking water pipes, *Journal of Hazardous Materials,* 160, 675-680.

[11] Raynaud, M., (2004), A view of the European plastic pipes market in a global scenario, *Proceedings of Plastics Pipes XII*, April 19–22, Milan, Italy.

[12] Kim, S., (2001), Pyrolysis kinetics of waste PVC pipe, *Waste Management*, 21, 609-623;

[13] Gari, D.W., Kozisek, F., (2008), Nickel and iron in drinking water in Czech Republic, *2nd International Conference "Metals and Related Substances in Drinking Water"*, Cost Action 637, Proceedings Book, 75-77;

[14] Flaten, T.P., (2001), Aluminum as a risk factor in Alzheimer's disease, with emphasis on drinking water, *Brain Res. Bull.,* 55, 187–196;

[15] Becaria, A., Lahiri, D., Bondy, S., Chen, D.M., Hamadeh, A., Li, H., Taylor, R., Campbell, A., (2006), Aluminum and copper in drinking water enhance inflammatory or oxidative events specifically in the brain, *Journal of Neuroimmunology,* 176, 16-23;