Do we really get rid of lead in drinking water since the outbreak in 2015?

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1. Introduction

Excessive lead has been found in drinking water in Hong Kong since the lead-water crisis happened in July 2015. Investigations by the HKSARG and various professional bodies have identified that the crisis in the public housing estates was caused by the problematic solders used in the plumbing and water supply systems. Recommendations on enhancing the quality control system of plumbing installations, practices and workmanships as well as strengthening the relevant legislations and water quality standards have thus been identified and developed in these two years by the relevant stakeholders.

2. What is lead?

Lead is a chemical element with atomic number 82 and symbol "**Pb**" (from the Latin "plumbum"). It is a heavy metal with a density exceeding that of most common materials; it is soft, malleable, and melts at a relatively low temperature. When freshly cut, it has a bluish-white tint; it tarnishes to a dull gray upon exposure to air. Lead has the second-highest atomic number of the classically stable elements and lies at the end of three major decay chains of heavier elements.

Lead has several properties that make it useful: high density, softness, low melting point, malleability, ductility, poor electrical conductivity (compared to other metals), relative inertness to oxidation (high resistance to corrosion due to passivation), and a propensity to react with organic reagents. Combined with relative abundance and low cost, these factors resulted in the extensive use of lead in construction, plumbing, batteries, bullets and shot, weights, solders, pewters, fusible alloys, and radiation shielding. In the late 19th century, lead was recognized as poisonous, and since then it has been phased out for many applications (such as lead pipes, etc.). Lead is a neurotoxin that accumulates in soft tissues and bones, damaging the nervous system and causing brain disorders and, in mammals, blood disorders.

3. Where does lead come from?

Lead exposure is a global issue as lead mining and lead smelting are common in many countries. Poisoning typically results from ingestion of food or water contaminated with lead, and less commonly after accidental ingestion of contaminated soil, dust, or lead-based paint. Seawater products can contain lead if affected by nearby industrial waters. Fruit and vegetables can be contaminated by high levels of lead in the soils they were grown in. Soil can be contaminated through particulate accumulation from lead in pipes, lead paint, and residual emissions from leaded gasoline.

The use of lead for water pipes is problematic in areas with soft or acidic water. Hard water forms insoluble layers in the pipes whereas soft and acidic water dissolves the lead pipes. Dissolved carbon dioxide in the carried water may result in the formation of soluble lead bicarbonate; oxygenated water may similarly dissolve lead as lead(II) hydroxide. Drinking such water, over time, can cause health problems due to the toxicity of the dissolved lead. The harder the water the more calcium bicarbonate and sulfate it will contain, and the more the inside of the pipes will be coated with a protective layer of lead carbonate or lead sulfate.

4. Existence of Heavy Metals in Nature

Heavy metals (such as lead) exist in nature and come from air, water, soil and food. In the heavily polluted environment, the amount of these heavy metals (such as lead) will be increased. To suit the different product needs, heavy metals (such as lead) may be added during the manufacture and thus found in the daily household products and consumables. Since the governments in many countries have already realized the serious effects and consequences of heavy metals (such as lead) impact to human health and environment, they have been set-up procedures to regulate the use of these kinds of products and consumables.

4.1 Heavy Metals in Water

Compared to other countries, Hong Kong has very strict guidelines to govern how much heavy metals (such as lead) can be present in tap water. It refers to the WHO 'Guidelines for Drinking Water Quality', Table A3.3 'Guideline values for chemicals that are of health significance in drinking water' such as heavy metals including Antimony (Sb), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), etc. The guideline values represent the concentration of constituents in drinking water that will not result in significant health risk to a standard person weighting 60 kg over a lifetime consumption of 2 litres per day for 70 years. Many developed countries such as EU, US, CA, AU, NZ, UK, etc. have set up their own national water quality standards based on the WHO Guidelines. To suit the local situations in difference countries, there are variations in the limiting values of certain water quality parameters (e.g. heavy metals such as lead) in drinking water. In terms of lead, WHO limit is 10 ug/l, which is less than that in US or PRC, where the limits are 15 ug/l and 50 ug/l respectively.

The following table is a summary of the maximum allowable contents of six heavy metals commonly found in drinking water being adopted in different countries:

Table A – Maximum Allowable Heavy Metal Contents in Drinking Water

Parameters (ug/l)*	WHO	EU	US	NZ	HK
Lead (Pb)	10	10	15	10	10
Cadmium (Cd)	3	5	5	4	3
Chromium (Cr)	50	50	100	50	50
Nickel (Ni)	70	20	100	80	70
Antimony (Sb)	20	5	6	3	20
Copper (Cu)	2000	2000	1300	2000	2000

*ug/l = ppm

Due to excessive lead level found in the potable water samples since the crisis in July 2015, WSD has issued WSD Circular Letter No. 1/2015 'Prohibition of Using Leaded Solder at Fresh Water Inside Services and New Parameters for Testing of Water Sample' to add four new parameters for testing of water samples, i.e. Lead (Pb), Cadmium (Cr), Chromium (Cr) and Nickel (Ni).

4.2 Metallic Lead in Plumbing Components

Lead is added to copper alloys such as brass and bronze, to improve machinability and for its lubricating qualities. Being practically insoluble in copper the lead forms solid globules in imperfections throughout the alloy, such as grain boundaries. In low concentrations, as well as acting as a lubricant, the globules hinder the formation of swarf as the alloy is worked, thereby improving machinability. Copper alloys with larger concentrations of lead are used in bearings. The lead provides lubrication, and the copper provides the load-bearing support.

The use of lead-based soldering to connect copper pipes for potable water use has been prohibited in Hong Kong since the 1980s. Copper pipe materials contain less than 0.1% impurities including lead. Copper alloy (brass or bronze) components containing a small percentage of lead such as valves, faucets and other fittings, which are manufactured to comply with the relevant BS, are commonly installed in the plumbing systems of buildings in Hong Kong. A small amount of lead, in particular for those copper alloy materials, a small amount of lead may leach and dissolve into the potable water due to corrosion (oxidation).

The maximum allowable lead contents of different plumbing products and materials being adopted in different countries are summarized in the following table:

Table B – Maximum Allowable Lead Contents in Plumbing Components

Components	EU(4MS)*	US	CA	AU	NZ	UK	HK
Copper Pipes	0.2%	0.25%	0.25%	0.05%	0.05%	0.085%	0.085%
Copper Alloy Gate Valves	0.2%	0.25%	0.25%	4.5%	4.5%	1-3%	1-3%
Copper Alloy Valves (Other) & Fittings	0.2%	0.25%	0.25%	4.5%	4.5%	4-6%	4-6%
Taps, Faucets & Mixers	0.2%	0.25%	0.25%	4.5%	4.5%	0.5-2.5%	0.5-2.5%
Solders	---	0.2%	0.2%	0.1%	0.1%	0.07%	0.07%
Weighted-Average	---	0.25%	0.25%	---	---	---	---

*EU(4MS) = Four Member States in EU

5. What is the meaning of "lead-free"?

According to WSD Circular Letter No. 1/2015 'Prohibition of Using Leaded Solder at Fresh Water Inside Services and New Parameters for Testing of Water Sample', it stipulates that the requirement of using "lead-free" solders for copper pipe joints in the fresh water inside services.

"Lead-free" solders in commercial use may contain tin, copper, silver, bismuth, indium, zinc, antimony, and traces of other metals. Most lead-free replacements for conventional Sn/Pb solder of 60%/40% and 63%/37% in proportion have melting points from 5 to 20 °C higher, though there are also solders with much lower melting points. "Lead-free" solder may be less desirable for critical applications, such as aerospace and medical projects, because its properties are less thoroughly known.

In plumbing applications today, lead is prohibited. Historically, a higher proportion of tin/lead-based solder was used, commonly 50%/50%. This had the advantage of making the alloy solidify more slowly. With the pipes being physically fitted together before soldering, the solder could be wiped over the joint to ensure water tightness. Although lead water pipes were displaced by copper when the significance of lead poisoning began to be fully appreciated, leaded solder was still used until the 1980s because it was thought that the amount of lead that could leach into water from the solder was negligible from a properly soldered joint. Since even small amounts of lead have been found detrimental to health, lead in plumbing solder was replaced by silver (food-grade applications) or antimony, with copper often added, and the proportion of tin was increased.

"Lead-free", by virtue of its meaning, does not practically mean that the lead content in a particular substance is equal to absolute "zero". According to Table 6 in BS EN 1254-1:1998 'Copper and copper alloys – Plumbing fittings – Part 1: Fittings with ends for capillary soldering or capillary brazing to copper tubes", soldering alloys with lead and brazing alloys with cadmium are "not" permitted in installations for water for human consumption. As for the soldering materials, UK and HK have set-up a stringent "lead-free" requirement of "0.07%" in accordance with Table 3 in BS EN ISO 9453:2014 'Soft solder alloys – Chemical compositions and forms (ISO 9453:2014)'. US and CA have the same lead-free limit of "0.2%" by weight while AU's and NZ's limit is "0.1%" by weight as shown in Table B.

6. Hong Kong Situation - Leaded Plumbing Components in Reality

In accordance with the Waterworks Regulations, CAP 102A, Reg. (2) & (20) and WSD Circular Letter No. 6/2015 'Application for Water Supply Pipes and Fittings Approval'; all plumbing materials which come into contact with the potable water including the pipes, joints, solders, valves, taps and other fittings shall comply with the relevant BS for potable water use. By referring to the relevant BS, it is not difficult to discover that most plumbing materials and fittings (e.g. copper alloy valves), which are produced from certain kinds of copper alloys (e.g. CC491K), may be possible to contain metallic lead up to 4-6% in content.
A summary of BS commonly adopted in the manufacture of various plumbing materials and fittings in the water supply systems is tabulated as follows:

Table C – BS Classification of Plumbing Materials and Fittings

Components	British Standards (BS)	Lead Content (%)
Copper Pipes	**BS EN 1057:2006+A1:2010** Copper and copper alloys. Seamless, round copper tubes for water and gas in sanitary and heating applications.	Copper pipes contain lead less than 0.085% (impurity).
Copper Fittings	**BS EN 1254-1:1998** Copper and copper alloys. Plumbing fittings. Fittings with ends for capillary soldering or capillary brazing to copper tubes. **BS EN 1982:2008** Copper and copper alloys. Ingots and castings.	Copper fittings contain lead less than 0.085% (impurity). Copper alloy fittings contain lead from 4% to 6%. Common copper alloys (e.g. CC490K & CC491K) contain approx. 5% lead.
Copper Alloy Valve	**BS 5154:1991** Specification for copper alloy globe, globe stop and check, check and gate valves. **BS EN 12288:2010** Industrial valves. Copper alloy gate valves. **BS EN 1982:2008** Copper and copper alloys. Ingots and castings.	Copper alloy valves contain lead from 4% to 6%. Common copper alloys (e.g. CC490K & CC491K) contain approx. 5% lead.

Taps, Faucets & Mixers	**BS EN 200:2008, BS EN 1286:1999, BS EN 1287:1999, BS EN 816:1997, BS EN 15091:2013**	Copper alloy taps & mixers contain lead from 0.5% to 2.5%.
Solder Alloys (Soft Solders)	**BS EN ISO 9453:2014** Soft solder alloys. Chemical compositions and forms. **BS EN 1254-1:1998** Copper and copper alloys. Plumbing fittings. Fittings with ends for capillary soldering or capillary brazing to copper tubes.	**Table 3:** Lead-free solder alloys contain lead less than 0.07% (impurity). **Table 6 Note:** Solder alloys with lead are not permitted to use for installations for human consumption.
Brazing Alloys (Hard Solders)	**BS EN ISO 17672:2010** Brazing. Filler metals. **BS EN 1254-1:1998** Copper and copper alloys. Plumbing fittings. Fittings with ends for capillary soldering or capillary brazing to copper tubes.	**Table 7:** Copper-Phosphorous-Silver brazing alloys contain lead less than 0.025% and zinc & cadmium less than 0.05% (impurity). **Table 6 Note:** Brazing alloys with cadmium are not permitted to use for installations for human consumption.

According to the "Report of the Task Force on Investigation of Excessive Lead Content in Drinking Water" published by the HKARG in October 2015, the Task Force has concluded the following findings:

1. Leaded solder joints were the cause of excess lead in drinking water; and
2. Copper alloy fittings also leached lead but did not result in excess lead in drinking water.

According to Table C, metallic lead with certain amount in content is present in the copper alloy plumbing materials and fittings and may "leach" lead into the drinking water either intermittently or continuously. Hence, drinking water remains a significant source of lead exposure impact to human health in the long term. Internationally, there is no commonly recognized safe blood level of lead. Also, lead leaching may not be directly proportional to the level of lead in the product or material itself.

7. Alternative Plumbing Materials & Jointing

Alternative piping materials such as stainless steel pipes, HDPE pipes, PPR pipes, etc. are not uncommon and may be considered for application.

Alternative mechanical pipe jointing methods such as compression joint, push-fit, press-fit, etc. for copper piping systems are quite common nowadays and may be considered for application.

Alternative materials for ingots and castings such as 4MS common approach's metallic materials, SDWA/NSF lead-free compliance's materials, lead-free brass or bronze, BiAlloy, Engineered Polymer, etc. may be the future trends in the plumbing industry.

8. Way Forward

In US's way, US adopts a performance-based approach in legislation by enacting the "Reduction of Lead in Drinking Water Act" on 04 January 2011 with effect on 04 January 2014 under the original "Safe Drinking Water Act" (SDWA) which defines the meaning of "lead-free" with 0.2% lead for solider & flux and 0.25% lead (weighted-average) for pipes & fittings.

Plumbing services certified to NSF/ANSI Standard 61 'Drinking Water System Components - Health Effects' - Annex G and NSF/ANSI Standard 372 'Drinking Water System Components - Lead Content' are considered fully in compliance with the lead-free content requirements of this Act (SDWA).

In EU's way, the Four Member States (MS) Germany, France, Netherlands and United Kingdom (4MS) have agreed on collaboration in the harmonization of tests for the hygienic suitability (i.e. safety) of products in contact with drinking water in January 2011, i.e. 4MS Common Approach.

According to the research carried out by the 4MS in 2011, if the lead content in copper alloy material can be controlled within 0.2%, then the lead content in drinking water should fall below 10ug/l. In 2013, UK adopted the 4MS standards in the Water Regulations for those metallic materials made for products in contact with drinking water.