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REMOVAL OF ORGANIC AND INORGANIC MICROPOLLUTANTS FROM DRINKING-WATER SOURCES

Report on a WHO Consultation

Siófok, Hungary
15-18 September 1987

1987

EUR/HFA target 20

TARGET 20

Water pollution

By 1990, all people of the Region should have adequate
supplies of safe drinking-water, and by the year 1995
pollution of rivers, lakes and seas should no longer
pose a threat to human health.

CONTENTS

1. Introduction

Considering that the quality of drinking water is being increasingly affected by the presence of organic and inorganic micropollutants which are of potential hazard to human health, several Ministries of Health and national water authorities in Europe have expressed their concern about the deterioration in the quality of both groundwater and surface water sources and have declared that this problem is one of the important priorities of the Water Decade Programme in Europe.

Moreover, the advances made in the last few years in analytical methods for the assessment of water quality have permitted not only the detection of a larger number of organic and inorganic micropollutants but also the determination of their actual concentration with a high degree of precision. In addition, the techniques for the removal of micro-contaminants have also evolved and several factors may affect the efficacy of a given method under different circumstances to the extent that some water treatment methods may induce other and more serious water quality problems.

Further, as a result of the industrial and agricultural expansion that is taking place in this continent, water resources are becoming scarce, particularly for domestic consumption. There is thus a growing need for the reclamation of contaminated water.

Therefore, the Regional Office for Europe of the World Health Organization, in cooperation with the Hungarian Institute for Water Pollution Control (VITUKI), decided to organize a Consultation to carry out an analysis of water treatment technologies which are currently employed for the removal of micropollutants from drinking-water sources.

A group of experts was convened from 13 European countries covering a wide range of professions such as biochemical engineers, biologists, chemical engineers, sanitary engineers, water managers, and microbiologists. In addition to VITUKI, a WHO/EURO Collaborating Centre on water pollution control and also the host institution, three other Collaborating Centres were also represented at the Consultation: the Veneto Region (Italy), the Water Research Centre (United Kingdom) and the National Institute of Public Health and Environmental Hygiene (Bilthoven, Netherlands). Two bodies responsible for waterworks, viz. Culligan Italiana S.p.a. (Italy) and Gentofte Sjaelsoe Municipal Waterworks (Denmark) were also represented at the meeting.

2. Presentations by countries

2.1 Austria

The main problem with micropollutants is the contamination of groundwater with volatile aliphatic halogenated hydrocarbons (per or trichloroethylene). Nitrates and pesticide residues together with iron and manganese are present in rural groundwater sources. In urban areas, because of industrial dumps, the groundwater is contaminated with ammonia, nitrates, mercury, arsenic, boron, cyanides, chlorinated solvents, phenols and mineral oil products.

Great emphasis is placed on preventing pollution by applying appropriate legislation, treating effluents, particularly those of industrial origin and by controlling the disposal of hazardous wastes. Whenever possible, a

contaminated source is replaced by an uncontaminated one, or by a less contaminated source, to lower the concentration of the pollutant to a permissible level.

Inorganic micropollutants (iron, manganese) are treated with oxidants sometimes combined with activated carbon filters. Biological methods are being studied taking into account the oxidation capacity of microorganisms. Organic pollutants are mainly removed by adsorption with activated carbon, or aeration combined with activated carbon filters. Techniques involving ionizing radiation are at an experimental stage.

2.2 Czechoslovakia

The principal problem micropollutants are oily substances, pesticides, detergents, phenols, iron, manganese, chromium, radioactive substances and chlorinated hydrocarbons.

Lower molecular weight oils can be removed effectively by intensive aeration whereas the higher molecular weight material responds to clarification assisted by flocculants. Ozonation and activated carbon adsorption have also been found to be very effective, and can also be used for the removal of pesticides, anionic detergents and phenols.

The majority of heavy metals are satisfactorily removed by alkaline clarification. Chromium (VI) is removable by alkaline coagulation with ferrous salts. Humic substances impede metal removal. When coagulation is not entirely successful adsorption by activated carbon can be used.

Radon is removed by intensive aeration, uranium by clarification and radium by adsorption techniques.

It has been recommended that steps are taken at water treatment plants to avoid the formation of haloforms by eliminating prechlorination, using alternative oxidants if necessary, by careful process control to ensure the optimal removal of humic substances and to chlorinate water only at the end of treatment when organics have been reduced to the minimum.

2.3 Denmark

Almost all drinking water is derived from groundwater sources and although many problems are avoided by selection of water abstraction areas, problems are increasing with the increasing contamination of groundwater resources.

Some micropollutants are of natural origin such as iron, manganese, ammonia, hydrogen sulphide, humic substances and methane. The problem pollutants derived from human activities include organic solvents, chlorinated hydrocarbons, chlorinated phenols, phenols and aromatic hydrocarbons.

Iron, manganese and ammonia are removed by cascade aeration and rapid sand filtration. Hydrogen sulphide and methane are also removed by aeration which has to be intensive at the higher concentrations encountered. No specific treatment has been adopted for the pollutants of industrial origin; the solution has been to abandon the affected sources or in a few cases, polluted groundwater sources are abstracted to relieve pollution of nearby abstraction sources.

The small fraction of surface water used for drinking water contains humic substances and these are removed by flocculation and sedimentation. In one plant, the organics are further reduced by ozone and granular activated carbon filters, followed by residual disinfection in the distribution system using preformed monochloramine.

2.4 Finland

The main problems stem from the high humus content of surface water and from the eutrophication of some surface water sources. On chlorination hazardous substances are formed as well as taste and odour. The principal measures have been focussed on the reduction of organo-chlorine compounds, both on trihalomethanes and the total amount of halogenated organics.

Contamination of groundwater by heavy metals or organic pollutants is rare, and has been dealt with by closing the affected sources.

Several water treatment plants have given up practising prechlorination, some carry out prechlorination periodically and some continuously during a short period in summer. Greater attention is being paid to non-volatile organochlorine substances because of mutagenicity.

The reduction of the content of organohalogen compounds has been by preventive measures including the elimination or reduction of prechlorination and the improved removal of organics. Two-stage chemical coagulation, ferric followed by alum, is used at three waterworks halving the final concentration of organics. Ozonation prior to the filtration stage and the use of chloramine as final disinfectants are also used with good results.

Among other organics, algal toxins can be a problem and these are treated by activated carbon. Powdered activated carbon (PAC) is favoured because of the reasonable costs and the seasonal requirement.

2.5 France

In the Paris region attention has been paid to providing means of warning of the imminence of pollution incidents. Monitoring stations have been set up on the rivers used for drinking-water supply by the respective water utilities to give a prior indication of water quality. Monitoring is of the more generalized parameters such as $-CH_2-$, phenols and absorbance at 254nm as well as of more specific analysis such as heavy metals by polarography. Warning is given when pollutants reach or exceed the maximum allowable concentrations.

Advanced analytical techniques are employed at central facilities to identify individual pollutants. A database has been established which gives information on each pollutant and the effectiveness of the different treatment processes in respect of each pollutant. The database can be interrogated by telephonic link and allows the treatment works to react appropriately to each pollution incident. For example, heavy metals except chromium are eliminated by coagulation, as are hydrocarbons. Cyanide is susceptible to preoxidation (ozone or chlorine). Chlorinated solvents require activated carbon adsorption or stripping. Adsorption will be by PAC in the case of the smaller plants.

Less conventional treatment is necessary in the case of certain chronic pollution, for example a combination of strong oxidants followed by granular activated carbon adsorption. These are still at an experimental stage.

2.6 German Democratic Republic

In general the micropollutants occurring in groundwater are determined by geological conditions. They include iron, manganese, ammonia, arsenic and humic substances. Chlorinated solvents, pesticides and herbicides are also present. Aluminium may be present in reservoir waters and a range of industrial and agricultural chemicals in river waters.

Aeration followed by slow sand filtration are applied for the removal of iron and manganese supplemented by permanganate addition, if necessary. Ammonia is usually removed by biological filtration following aeration. Arsenic is flocculated with ferric chloride.

Reservoir waters are treated by alum flocculation, filtration and disinfection. This treatment is supplemented by groundwater recharge, biofiltration and activated carbon adsorption in the case of river waters. Powdered activated carbon is added prior to filtration to treat taste and odour.

Pesticides and herbicides are controlled by means of drinking-water protection zones and a limitation on the products which can be used.

2.7 Hungary

Micropollutants of concern may be of natural geological origin or be due to pollution, and may be inorganic or organic. Among the former are the heavy metals, arsenic, and ammonia. Among the latter are petroleum products, phenols, surfactants, pesticides, humid acids and trihalomethanes (THMs) and chlorophenols produced during the disinfection of water.

Micropollutants present in solid form or adsorbed on suspended solids can be removed by simple liquid-solid phase separation techniques. The great bulk of micropollutants are, however, present in dissolved form, in both surface waters, bank-filtration well waters and groundwaters contaminated by unregulated waste dumps.

Methods involving oxidation and adsorption are in common use for the removal of organic micropollutants. No treatment method is used at present for the selective removal of any particular substance. Treatment objectives are to remove as much organic material as possible in the coagulation-flocculation stage to reduce the amount to be treated by the more expensive oxidation and adsorption stages.

Powdered activated carbon recycling has proved to be very effective in the removal of organics from drinking water.

Heavy metals are satisfactorily removed during coagulation and subsequent solids removal. Arsenic requires an oxidation step and chromium (VI) requires a reduction step prior to the coagulation stage for adequate precipitation. Metals present as organic complexes should be regarded as organic micropollutants.

2.8 Italy

The most common micropollutants include iron, manganese, ammonia, hydrogen sulphide, nitrite, methane and humic acids, all of which occur

naturally and chlorinated solvents, herbicides and pesticides, and heavy metals which are due to environmental pollution.

Other natural pollutants such as arsenic, fluoride, barium and potassium are more localized. In addition, there are the micropollutants which arise during water treatment including halogenated organics, aluminium and products of corrosion of water mains and plumbing.

The principal treatment techniques used for the control of organic micropollutants are adsorption with granular activated carbon for organics such as chlorinated compounds and pesticides, packed tower aeration including vacuum stripping for volatile substances including THMs, air oxidation and precipitation for the removal of iron, manganese and other heavy metals, and sand filtration and halogen disinfection.

For the treatment of surface waters direct filtration, coagulation and sedimentation, adsorption by activated carbon both PAC and granular activated carbon (GAC) and ozonation are employed. The last two are preferred for the more dangerous pollutants and for the removal of colour, taste and odour.

2.9 Netherlands

Two-thirds of drinking water is from groundwater sources and one-third from surface water. Storage of river water in open reservoirs and underground storage in dunes is used to tide over periods of accidental pollution of the river water.

Depending on the type of storage, two water treatment schemes are in operation:

(a) storage in open reservoirs: reservoir, coagulation/sedimentation, ozone, rapid sand filtration, GAC filtration, chlorination;

(b) dune storage: coagulation/sedimentation, rapid sand filtration, dune recharge, aeration, PAC, rapid sand filtration, slow sand filtration, (and occasionally) chlorination.

Studies of the behaviour of organic micropollutants during treatment processes have been focussed particularly on halogenated organics, expressed as adsorbable halogenated organic compounds (AOX), extractable halogenated organic compounds (EOX), THMs and mutagens.

The most effective and reliable process for the removal of mutagens and most of halogenated compounds appears to be GAC filtration. Groundwater recharge also removes mutagens and some halogenated compounds effectively. Nevertheless, only by a proper combination of treatment processes can acceptable water quality be produced.

2.10 Poland

A survey of drinking water in the 36 largest towns and conurbations supplied by 63 waterworks showed that trihalomethanes exceeded the recommended maximum concentrations in 9 cases. At their locations, steps were taken to reduce the THM levels by preventing THM formation rather than by attempting to remove them. A formation potential was established depending on the treatment characteristics of individual treatment plants.

Various changes in prechlorination technique were found to be useful in reducing THM formation potential including reducing the prechlorination dose, dechlorination following prechlorination and reducing contact time.

Coagulation prior to chlorination reduced trihalomethanes formation potential (THMFP) particularly with high coloured groundwater. This arises from the removal of THM precursors.

The use of chlorine dioxide as a substitute for chlorine dramatically reduced THM formation. Ozonation had a similar effect. Potassium permanganate and PAC were found to have no effect on THMFP.

Granular activated carbon was found to be effective for THM removal when fresh but breakthrough occurred quite quickly.

Very good reduction in THM concentration in finished water was achieved in practice by combination of preozonation, coagulation, rapid filtration, GAC filtration and final chlorination.

2.11 Portugal

The European Community Directive of 16 June 1975 (75/440) on Quality Requirements for Surface on Water Intended for the Abstraction of Drinking Water is followed and the appropriate treatment applied to water according to the various quality classifications specified in the Directive.

There is considerable concern with the selection and protection of good quality water sources. The policy is to avoid pollution and to change to alternative sources rather than to treat poor quality waters. There is thus no requirement for treatment specifically aimed at the removal of micropollutants. As a consequence, a careful analytical control of water quality is kept, either on raw or finished water.

2.12 Romania

The quality of a number of water resources has been affected by the presence or the increase in the concentration of various micropollutants including ammonia, hydrogen sulphide, copper, lead, zinc and trihalomethane precursors.

Efficient and economic solutions and methods were sought for the removal of these pollutants, and are now being introduced into water treatment technology.

Ammonia is removed by biological oxidation to nitrate using nitrifying bacteria. This is carried out in trickling filters containing granular activated carbon media. Hydrogen sulphide is also removed by biological oxidation using the same technique.

The removal of the heavy metals, copper, lead and zinc is achieved by coagulation with ferric or aluminium sulphates and lime followed by filtration through a weakly acidic ion exchange resin. The process is highly efficient but greatly increases the cost of the water.

Treatment for the removal of trihalomethanes and their precursors becomes necessary when the concentration of trihalomethanes exceeds 0.1 mg/l in final water. The treatment sequence chosen was coagulation with aluminium sulphate,

sedimentation, rapid sand filtration, ozonation and adsorption by granular
activated carbon. Small doses of chlorine are used for final chlorination.

2.13 United Kingdom

Among the micropollutants of current concern are volatile organic
compounds principally industrial solvents which have contaminated goundwater,
by-products of disinfection including trihalomethanes and other mutagenic
organochlorine compounds, and pesticides and herbicides.

In addition, radon is a problem in certain areas, and lead in drinking
water in other areas derived from domestic plumbing where the water is soft,
acidic and plumbosolvent.

While any of the currently used water treatment processes may be
effective in some way against them, two techniques are in use specifically to
remove micropollutants. Pack tower aeration is employed for volatile organics
in some cases and for radon. Activated carbon filters are used to remove
other organics. Ozonation is also in use to control taste and odour.
Chemical coagulation is used for the removal of turbidity and humic substances
which are precursors of THMs.

Packed tower aerators are simple to operate and are usually much cheaper
than activated carbon adsorption. Both these techniques are probably cheaper
than finding an alternative source and having to lay new water mains.

Measures are taken to reduce plumbosolvency by central water treatment,
in the form of adjustment of pH or alkalinity and by phosphate dosing to
produce protective coatings on lead pipes.

3. Technical discussions on organic micropollutants (subgroup I)

Among the many organic pollutants likely to occur in drinking water, the
panel selected groups of organic substances that have been of the greatest
concern. These substances were examined for their treatability by the
commonly used treatment processes. General recommendations on which course of
action should be taken as regards organic micropollutants are given.

3.1 Selection of priority micropollutants

The following organic substances were taken into consideration, and the
following priorities have been set:

3.1.1   Natural substances occurring in water resources

Humic substances	+ a
Methane	none

Humic substances as such are not thought of as micropollutants, but
by-products resulting from their chlorination are. They are dealt with in the

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a Ratings are as follows: None = no concern
+ to +++ = moderate to great concern
respectively

group "Reaction products from chlorination". Humic substances can be removed by the usual treatment processes (coagulation, adsorption).

Metabolites of living organisms   +

3.1.2 Anthropogenic micropollutants

Chlorinated solvents   +++
Pesticides and herbicides   +++
Polycyclic aromatic hydrocarbons (PAHs)   +
Oil derivatives   ++
Chelating and surface active agents   ++
Polychlorinated biphenyls (PCBs)   +
Phenols   ++

As far as PCBs are concerned, limited information is available in some countries where this problem is still under investigation.

3.1.3 Micropollutants resulting from water treatment and distribution

(a) Reaction products from chlorination

Volatile   ++
Non-volatile   +++

(b) Reaction products from other strong oxidants (ClO_2, O_3, $KMnO_4$, H_2O_2)   +++

(c) Coagulation and filtration aid residuals   +

3.1.4 Metal complexes with humic substances   +

3.1.5 Organic substances from leaching of materials of the distribution network (vinyl chloride, PAHs, phthalates   ++

On the basis of these priorities, four groups of micropollutants were selected for a thorough examination of the methods of their control and removal:

- chlorinated solvents;
- pesticides and herbicides;
- non-volatile reaction products of chlorination;
- reaction products of other strong oxidants.

It must be borne in mind however that concern for the other groups of micropullutants named above may be on the increase.

3.2 Process assessment

In this section, the most commonly used treatment processes are reviewed with respect to the advantages and disadvantages related to their use, and with respect to their impact on micropollutant removal (either beneficial or detrimental).

3.2.1 Granulated activated carbon (GAC)

This is by far the technique which is most frequently used for micropollutant control. It has the following advantages:

- reliability under most conditions;
- a wide range of applicability;
- a smoothing or damping effect on pollution peaks.

The disadvantages of this process are:

- high overall cost;
- qualified personnel are needed to run the process properly;
- it needs close control;
- under current treatment practice, the adsorbent is short-lived.

3.2.2 Powdered activated carbon (PAC)

This technique also relies on adsorption, but its operating mode is different, as the PAC is wasted. Its advantages are:

- it can be used as an emergency procedure;
- it is adequate when only low activated carbon dosages are required;
- low investment cost.

Its disadvantages are:

- PAC is necessarily associated with a solid/liquid separation stage;
- PAC is less applicable to cases of high organic loads;
- sludge disposal requirements.

3.2.3 Coagulation and clarification

This widespread spread process has the following advantages:

- it is efficient for the removal of high molecular weight organics;
- a substantial part of the organics are removed, including micropollutants;
- efficient in combination with GAC.

On the other hand, this process has the following drawbacks:

- the requirement for complementary treatment in the case of polluted resources;
- only partial removal of organics is commonly achieved;
- the presence of coagulant residuals in treated water;
- sludge disposal requirements.

3.2.4 Chlorination

This process is very widely used, as final disinfection at least. It may oxidize some micropollutants, but it has the following disadvantages:

- it produces halogenated organics, and taste and odour causing substances.

3.2.5 Oxidation

This refers to the use of oxidants other than chlorine, i.e., ozone, chlorine dioxide, etc.

The following advantages can be cited:

- many micropollutants can be oxidized by these agents;
- these techniques reduce the final chlorine demand;
- their combination with other processes such as adsorption or biological processes can be beneficial to organics removal.

However, these are the following drawbacks:

- both organic and inorganic harmful by-products may be formed;
- they may enhance the THMFP (trihalomethane formation potential);
- they increase the organic matter biodegradability (problems of bacterial reviviscence);
- high cost.

3.2.6 Aeration (air stripping)

This process has the following favourable features:

- moderate costs;
- it removes the volatile compounds;
- there are ño by-products.

On the other hand:

- it transfers the pollution to the atmosphere;
- the water may become contaminated by the air.

3.2.7 Other adsorbents

Techniques are still under investigation and the available information is not conclusive. More data and more knowledge are needed on their potential application to micropollutant removal.

3.2.8 Sand filtration

Filtration as such is not effective for organic micropollutant removal. This process as such has neither advantages nor disadvantages for micropollutant removal.

3.2.9 Biological processes

Their efficiency as processes for the removal of micropollutants is not well enough documented for any recommendations to be made. Nevertheless their potental usefulness should not be ignored. More experience is needed, especially in the drinking water field.

The disadvantages are:

- susceptibility to poisoning;
- slow start up;

- sensitivity to temperature changes;
- sensitivity to shock load.

3.2.10 Bank filtration and artificial groundwater recharge

These techniques are effective for the removal of specific micropollutants. However, they strongly depend on local conditions.

The following table summarizes the efficiency of the processes examined above, with respect to the removal of the four selected groups of micropollutants.

PROCESSES	CHLORINATED SOLVENTS		PESTICIDES HERBICIDES		NON-VOLATILE PRODUCTS OF CHLORINATION	REACTION PRODUCTS OF OTHER OXIDANTS
	G	S	G	S		
Granular activated carbon	++	+	(++)	(+)	++	+
Powdered activated carbon and filtration	+	+	(+)	(+)	++	+
Coagulation	0	(+)	(0)	(+)	+	(+)
Chlorination	0	0	0	0	-	-
Oxidation	(+)	(+)	(+)	(+)	+	+ 1) -
Aeration (air stripping)	++	++	0	0	0	0
Other adsorbents	?	?	?	?	+	(+)
Sand filtration	0	0	0	0	0	0
Biological processes	+	+	(+)	(+)	+	+
Bank filtration Artificial groundwater recharge	+	+	+	+	+	+

++ very efficient   - detrimental   G = groundwater
+ efficient.   () uncertain effect   S = surface water
0 no efficiency   ? insufficient data

1) peroxidation +, otherwise uncertain effect

4. Technical discussions on inorganic micropollutants (subgroup II)

The Consultation recommends two groups of inorganic pollutants to be taken into consideration. The first group is for immediate study and the second one for future study.

I	II
Aluminium Ammonia (NH_3) Arsenic Cadmium Chromium (III) and (VI) Copper Iron Lead Manganese Mercury Nickel Zinc	Asbestos fibers Barium Fluoride Inorganic pollutants due to increased acid rain Nitrate (refer to .....) Radioactive material

Group I is divided into three subgroups depending on the main source of origin. The classification is of course subject to geographical variations.

A	B	C
Naturally occurring pollutants	Micropollutants arising from human activity	Micropollutants originating from inadequate water treatment
Turbidity Arsenic Iron Manganese Ammonia Aluminium	Copper Cadmium Mercury Lead Zinc Nickel Chromium III Chromium VI Ammonia	Aluminium Lead Cadmium Copper Zinc

4.1 Metal coagulants in water treatment

Generally speaking, iron salts are to be preferred as coagulants for the following reasons:

- aluminium residuals in water are of concern to human health, particularly in relation to renal dialysis patients;

- aluminium salts need careful pH control since there is an optimum operating pH for limiting aluminium solubility;

- sludge containing aluminium presents some speical disposal problems.

Nevertheless, aluminium salts could be preferred under certain circumstances when the operating pH is low (below approx. 7.2).

4.2 Polyelectrolytes in water treatment

Since polyelectrolytes can bring about large savings in metal coagulant doses, thereby reducing the risk of residuals, the Consultation recommends further studies in order to establish an acceptance protocol for natural and synthetic polymers in relation to their effects on human health.

4.3 Naturally occurring pollutants

4.3.1 Arsenic

(a) Oxidation of arsenic (III) to arsenic (V) is the first step of the treatment, in reducing the toxicity of arsenic and making it more amenable to removal by coagulation and adsorption.

(b) Arsenic can be removed with suitable coagulation and solid-liquid separation technology. Direct filtration is a generally available technology and can reduce investment and running costs.

(c) Both iron and aluminium salts can be used. Iron salts are preferred because of their large range of suitable pH operating conditions.

4.3.2 Ammonia

(a) The most common technology for ammonia removal has been break-point chlorination. The increasing concern about haloform formation due to chlorination practice has promoted much research regarding alternative technologies for ammonia removal. All of them, even if very efficient, present some problems such as investment cost, careful maintenance, etc.

(b) Nowadays, alternative disinfectants to chlorine can assure good microbiological protection even in the presence of ammonia and the reasons for ammonia reduction are therefore declining. A new approach should be made in setting a limit to this parameter.

(c) More research is needed on the significance of ammonia in two fields:

- Corrosion problems with copper and copper alloys;

- The effect of ammonia on the growth of bacteria in distribution systems.

4.3.3 Iron and manganese

(a) Present technology (oxidation, filtration and sedimentation-filtration) is suitable and reliable. If chemical oxidants are to be used, it is suggested that break-point chlorination is avoided. Chloramination and potassium permanganate, chlorine dioxide and other oxidants not generating haloforms should be considered.

(b) Due to distribution problems (e.g. corrosion and bacteria growth) WHO should examine the possibility of reducing the recommended concentration for iron to below $50mg/m^3$ and for Mn to below $20mg/m^3$.

(c) Present technology can generally reach this target but economic factors must be considered (e.g. increased filtration capacity, more backwash water needed).

4.3.4 Turbidity

Disinfection efficiency is strongly connected with turbidity and some micro-organisms are more easily removed by filtration rather than by chemical disinfection. For these reasons, it is recommended that a filtration step should be included after any sedimentation or when turbidity normally exceeds 1 nephelometric turbidity unit (NTU) or when disinfectant-resistant microorganisms are detected in raw water (e.g. spores, cysts, algae, etc.).

4.4 Heavy metals: cadmium, copper chromium III, lead, mercury, nickel, zinc

(a) The Consultation recommends that WHO should reconsider the need for setting a guideline value for nickel. A Maximum Concentration Level (MCL) of $100mg/m^3$ is suggested.

(b) In lowering heavy metal concentrations to below their MCLs, water alkalinity and pH are important factors. If alkalinity exceeds 100 mg/l as HCO_3, coprecipitation with ferric and aluminium hydroxides result in a heavy metal removal to below the MCLs by operating at neutral-basic pH (between 7 and 8.5), except nickel which requires pH approx. 9. In the case of low alkalinity, it is suggested that pH and alkalinity are increased using appropriate chemicals.

(c) Chromium (VI)

For chromium (VI) removal, two steps are required before precipitation:

(i) reduction of chromium (VI) to chromium (III) with ferrous salts at about neutral pH (6.5-8.5)

(ii) oxidation of excess ferrous iron with suitable chemicals.

4.4.1 Other options

The literature presents alternative methods for heavy metals removal (e.g. ion exchange, adsorption of organic complexes, reverse osmosis, chromium (VI) reduction by activated carbon, sulphide precipitation, etc.) but all of them appear complicated and expensive and may be inappropriate for drinking-water treatment.

4.4.2 Organic complexes of heavy metals

If heavy metals are present in raw water as organic complexes, alternative methods of treatment must be considered:

(a) Destruction of the complexes with strong chemical oxidants (e.g. ozone, photochemical oxidation, etc.) prior to heavy-metal removal.

(b) Direct adsorption of complexes by activated carbon.

4.5 Micropollutants originating from inadequate water treatment

(a) Aluminium

Excessive aluminium residuals are due to inadequate control of the coagulation process, particularly pH control.

The Consultation recommends careful process design and suitable monitoring in order to overcome the problem. If possible, ferric salts are preferable as alternative coagulants.

(b) Heavy metals (cadmium, copper, lead, zinc) resulting from corrosion

The Consultation recommends that before water is put into distribution, appropriate action is to be taken to avoid pipe corrosion (e.g. pH correction, increase of buffer capacity and of alkalinity).

5.1 Conclusions and recommendations (subgroup I, organic micropollutants)

1. The prevention of pollution and the protection of water resources (protection zones, structures, etc.) are still the most effective way to preserve the quality of drinking water. Therefore, non-conventional treatment procedures and sophisticated treatment technologies cannot be considered as alternatives to the prevention of pollution and the protection of water resources.

2. No single treatment technology for complete removal of the organic micropollutants yet exists. For production of safe drinking water, a combination of proper technolgies must be made.

3. Further investigation should be initiated to replace those water treatment technologies which themselves give rise to additional pollution.

4. When developing treatment methods for the removal of micropollutants that are hazardous to human health, the possible creation of other health risk factors, both chemical and microbiological, must be taken into consideration.

5. In connection with the possible use of chlorine dioxide as a promising alternative for chlorination, guidelines for residual concentrations of chlorine dioxide, chlorite and chlorate in drinking water should be set.

6. Data from mutagenicity tests might be used as an important criterion for the assessment of an overall health risk associated with drinking water pollution. Therefore, more information on relationships between the data, the mutagenicity tests and human health hazards should be sought.

7. Although previous attention has been focussed on non-polar or moderately polar organic micropollutants, recent studies have revealed health hazards associated with some other, mostly highly polar compounds, such as halogenated organic acids, organic N-chloro-compounds, MX[a], etc. Proper analytical methods and more information on the health impact of these types of compound are urgently required.

8. The contribution of micropollutants from distribution systems has not been discussed during the Consultation. Nevertheless, there is a growing concern related to the influence of networks on drinking water quality, particularly as a growing variety of chemicals and materials are used, as such or in combinations.

5.2 Conclusions and recommendations (subgroup II, inorganic micropollutants)

Concerning inorganic micropollutants, the Consultation discussed the advantages and disadvantages of the methods of removal of: arsenic, ammonia, iron and manganese, nickel, chromium aluminium, organic complexes of heavy metals and heavy metals resulting from corrosion. The following recommendations were made:

1. Iron salts are generally preferable to aluminium salts as coagulants.

2. Aluminium salts could be preferred when the operating pH is low.

3. Further studies on polyelectrolytes are needed in order to establish an acceptance protocol for natural and synthetic polymers in relation to their effects on human health.

4. Both iron and aluminium salts can be used for the removal of arsenic. Iron salts are preferred because of their large range of suitable pH operating conditions.

5. Development of alternative technologies to break-point chlorination is needed for the removal of ammonia because of the concern over haloform formation.

6. More research is needed on the significance of ammonia in two fields:

(a) Corrosion problems with copper and copper alloys;
(b) The effect of ammonia on the growth of bacteria in distribution systems.

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[a] Chlorinated furanones

7. Because of distribution problems (e.g. corrosion and bacteria growth) WHO should examine the possibility of reducing the recommended concentration for iron to below $50mg/m^3$ and for Mn to below $20mg/m^3$.

8. A filtration step should be included in water treatment after any sedimentation step or when turbidity normally exceeds 1 nephelometric turbidity unit (NTU) or when disinfectant-resistant microorganisms are detected in raw water (e.g. spores, cysts, algae, etc.).

9. WHO should reconsider the need for setting a guideline value for nickel. It is suggested that the Maximum Concentration Level (MCL) should be set at $100mg/m^3$.

10. When heavy metal concentrations exceed the MCL, water alkalinity and pH must be taken into account.

11. If heavy metals are present in raw water as organic complexes, modified methods must be considered for effective treatment:

(a) Destruction of the complexes with strong chemical oxidants (e.g. ozone, photochemical oxidation, etc.) prior to heavy-metals removal.

(b) Direct adsorption of complexes by activated carbon.

12. Excessive aluminium residuals are due to inadequate control of the coagulation process, particularly pH control. Careful process design and suitable monitoring are recommended to overcome the problem. If possible, ferric salts are to be preferrred as coagulants.

13. Before water is put into distribution, appropriate action should be taken to avoid pipe corrosion (e.g. pH correction, increase of buffer capacity and of alkalinity).

Annex 1

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