WATER AND WASTEWATER TREATMENT

Eduard G. Novitsky
Institute of Chemical Machinery Industry "NIICHIMMASH," Moscow, Russia

Ruslan Kh. Khamizov
Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow, Russia

Keywords: water quality; water standards; sources of waste water; processes for water treatment; equipment for water treatment; preparation; water supply; water purifying; waste water purifying

Contents

Summary

Problems of supplying the population with drinking water of high quality assume ever-greater importance because of the development of an environment which is polluted (including its water) by industrial waste products. The substances which are now found in surface and ground water are very various in different world regions because of many factors: the types of industrial and agricultural processes in the water accumulation area, the quantity and quality of water treatment constructions, pretreatment technologies of drinking water, and wastewater purification. The level of contamination in water sources is so high that water can no longer be considered as a harmless natural product; it demands special treatment and control.

The theme considers modern demands, standards, and other requirements on the quality of drinking water, and water for industry and agriculture. Also modern analytical methods of water quality in laboratory and field conditions are described, and tendencies in the increase of demand for water quality are formulated.

The sources and composition of municipal, agricultural, and industrial wastewaters, and assessments of surface and ground water pollution, are discussed, with the purpose of formulating problems and methods of wastewater treatment. The main processes of water treatment (including filtration, flotation, sedimentation, coagulation and flocculation, processes of sorption, ion exchange, membrane separation, X-ray techniques, electric, chemical and biological treatment) are considered in detail. The principal processes, implementations and materials are described. Centralized and local water supply methods which make use of these technologies are described, together with water treatment processes widely used in the world. The features of water supply with water pretreatment for agricultural and industrial enterprises (heavy, food, electronics etc.) are considered. Technological schemes for clarifying municipal, agricultural, and industrial wastewater, methods of treatment, and methods of reuse of the waste products, are also considered in detail. Recycling water systems used for different purposes are discussed. Finally, legal aspects of water supply are considered.

1. Introduction

The earth's reserves of water, estimated at approximately 1.4 billion cu km, may seem enormous. However, practically 97.5 percent of these reserves are saline, of little use for consumption, including the waters of the oceans that comprise 96.5 percent of the entire quantity and the reserves of highly mineralized underground brines that constitute about 1 percent (13 million cu km). Thus the freshwater component is only 2.5 percent of all the reserves, and two-thirds of this is in frozen glaciers, mainly in the Arctic and Antarctic regions. There is only 10.5 million cu km of liquid freshwater on the globe. Practically the whole of this water is underground and currently difficult to access. Only 135,000 cu km of freshwater, or 0.01 percent of the world's aquatic resources, is readily accessible. This includes water in rivers, lakes, marshes, and the soil, as well as water in the atmosphere which is in a state of continuous circulation.

All this freshwater participates in a perpetual natural process of circulation, which is estimated to involve about 525,000 cu km per year. This circulation of water is in essence a global water purification and water desalination process, carried out on a giant and eternal scale by a perpetual natural distiller. The functioning of this distiller consumes one-fifth of all the energy from the sun that reaches the surface of the earth. Each year a layer of water with an average thickness of 1,250 mm evaporates from the surface of the oceans.

The most important source of freshwater available for humankind is the fluvial waters, the annual perpetual volume of which comprises about 40,000 cu km. In recent decades the pattern of worldwide water supply and consumption has begun to indicate that freshwater could prove to be the most critical resource for the whole of humanity, unless very energetic measures are soon undertaken. The water supply per capita has reduced, and the rate of water consumption increased, as shown in Figure 1. If these tendencies are not corrected, the global water crisis, which will impose severe limitations on the economic development of most countries, could be with us as early as in the middle of the twenty-first century.

The central water shortage problem is that the human population of the earth has already reached 6 billion and is still growing. One of the most serious issues is the deterioration of accessible surface water as a result of the pollution of aquatic resources by industrial and agricultural wastes. At the same time, water consumption has shown a drastic increase associated with industrial development and an increase in the area of irrigated agricultural land.

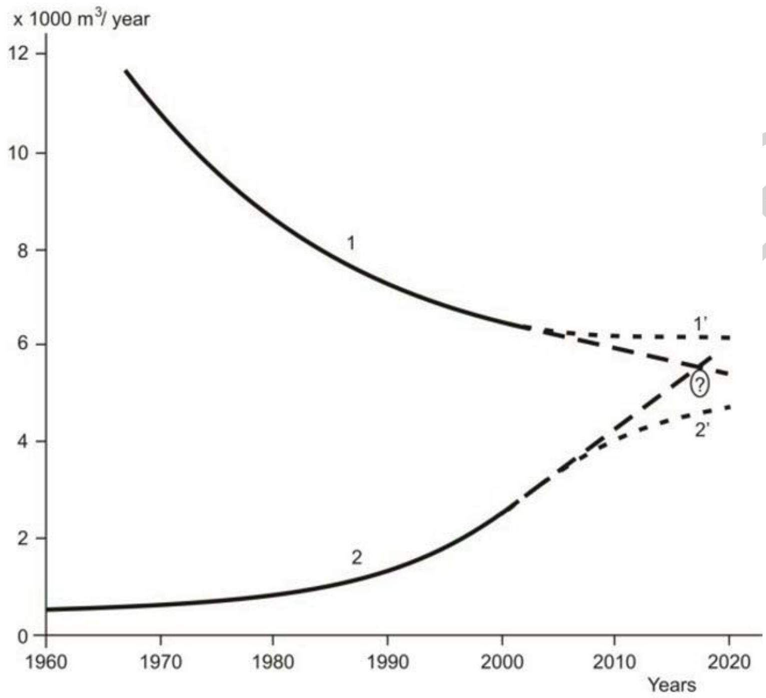

Figure 1. Available water supply (1) and water consumption (2) per capita of the earth's population, 1960–2000, with extrapolations to 2020. 1' – possible future supply if alternative water sources are located and used and contaminated sources are remediated. 2' – possible future usage if the rate of population growth slows and water-saving industrial and agricultural technologies are developed.

In the year 1900, the overall consumption of pure water in the world was 400 cu km; in 1990 it was approximately 8,000 cu km. Domestic demand accounted for only 6 percent of this amount. Meeting the needs of industry demanded 25 percent, and 65 percent was used for irrigation, while 4 percent was lost through evaporation from artificial water basins and lakes.

The overall consumption of pure water in the world in the year 2000 was 15,000 cu km. Three-fifths of this amount was used for the dilution of industrial wastewater, and in agriculture. Global water consumption continues to grow steadily, despite the gradual shift in developed countries to novel technologies such as water recycling systems, and despite much effort in the field of conservation and economic use of aquatic resources.

2. Water Quality Regulations and Standards

Water quality standards have been developed by various national, regional, and international bodies, as well as by the World Health Organization (WHO). Each national organization for standards has a legal right to issue regulations affecting its own country, and after confirmation by governments these become mandatory.

International regional organizations have similar rights for standardization of water quality within the countries participating in appropriate international and intergovernmental agreements. For instance, in 1980 the European Union adopted a Directive on Potable Water, which is mandatory for fifteen European countries. A special body set up by the EU, bringing together specialists from participating countries, works continuously to improve and develop the Directive. It regularly publishes other normative documents, including a *List of the Contaminants of Water Subject to Monitoring and Control*. The water quality standards developed by the US Environment Protection Agency are applied in the countries of the North American Free Trade Association (NAFTA). Another example is the national standards for water quality developed in the former USSR, which have been adopted as national standards in the majority of countries of the former Soviet Union.

Lists of priority pollutants and their maximum permissible concentration in water intended for use in industry and agriculture, as well as the corresponding standards for wastewaters of various origins, are usually regulated through national and regional international standards.

Taking into consideration the importance of the quality of potable water for the health of human beings, basic water quality standards have been developed by the World Health Organization (WHO). These recommendations are published in the *Guidelines for Control and Quality of Potable Water* issued in English, French, and Russian. Table 1 lists the WHO-recommended maximum concentrations of various substances.

Component	**Unit of measure**	**Standard (not more)**	**Component**	**Unit of measure**	**Standard (not more)**
Inorganic components			**Inorganic components**		
Mercury	mg l^{-1}	0.001	Boron	mg l^{-1}	0.3
Cadmium	mg l^{-1}	0.003	Iron	mg l^{-1}	0.3
Antimony	mg l^{-1}	0.005	Barium	mg l^{-1}	0.7
Arsenic	mg l^{-1}	0.01	Copper	mg l^{-1}	1.0
Lead	mg l^{-1}	0.01	Ammonium	mg l^{-1}	1.5
Selenium	mg l^{-1}	0.01	Fluor	mg l^{-1}	1.5
Nickel	mg l^{-1}	0.02	Nitrites	mg l^{-1}	3.0
Hydrogen sulfide	mg l^{-1}	0.05	Zink	mg l^{-1}	3.0
Chromium	mg l^{-1}	0.05	Nitrates	mg l^{-1}	50.0
Molybdenum	mg l^{-1}	0.07	Sodium	mg l^{-1}	200.0
Cyanides	mg l^{-1}	0.07	Sulfates	mg l^{-1}	250.0

Manganese	mg l^{-1}	0.1	Chlorides	mg l^{-1}	250.0
Aluminum	mg l^{-1}	0.2	pH (optimum)	unit of pH	6.5—8.5
Organic components			**Pesticides**		
Epichlor-ohydrine	μg l^{-1}	0.4	Aldrin	μg l^{-1}	0.03
Acrilamide	μg l^{-1}	0.5	Heptachlor	μg l^{-1}	0.03
Benzo[a]pyr-ene	μg l^{-1}	0.6	Chlordan	μg l^{-1}	0.2
Benzene	μg l^{-1}	0.7	Hexachloro-benzene	μg l^{-1}	1.0
Carbon tetrachloride	μg l^{-1}	2.0	Atrazine	μg l^{-1}	2.0
Hexachlorob-utadiene	μg l^{-1}	5.0	DDT	μg l^{-1}	2.0
Vinylchloride	μg l^{-1}	10.0	Lindan	μg l^{-1}	2.0
Dichlorom-ethane	μg l^{-1}	20.0	Carbofuran	μg l^{-1}	5.0
Styrene	μg l^{-1}	20.0	Molinate	μg l^{-1}	6.0
Trichloroben-zenes	μg l^{-1}	20.0	Isoproturon	μg l^{-1}	9.0
1,2-Dichlor-oethane	μg l^{-1}	30.0	Pentachlor-ophenol	μg l^{-1}	9.0
Tetrachlor-oethylene	μg l^{-1}	40.0	Silvex	μg l^{-1}	9.0
Trichloroeth-ylene	μg l^{-1}	70.0	2,4,5-T	μg l^{-1}	9.0
1,4-Dichlor-obenzene	μg l^{-1}	300.0	Aldicarb	μg l^{-1}	10.0
Chlorobenz-ene	μg l^{-1}	300.0	Metholachlor	μg l^{-1}	10.0
Xylenes	μg l^{-1}	500.0	Tekoprop	μg l^{-1}	10.0
Toluene	μg l^{-1}	700.0	Propanyl	μg l^{-1}	20.0
1,2-Dichlor-obenzene	μg l^{-1}	1 000.0	Chlorotoluran	μg l^{-1}	30.0
1,1,1-Trichloro-ethane	μg l^{-1}	2 000.0	Pyridat	μg l^{-1}	100.0
Components after water disinfection			**Water radioactivity**		
Trichloroacetal-dehyde	μg l^{-1}	10.0	Total α-radioactivity	Bk l^{-1}	0.1
Dichloroacetic acid	μg l^{-1}	50.0	Total β-radioactivity	Bk 1^{-1}	1.0
Trichloroacet	μg l^{-1}	100.0			

ic acid					
Chlorine		5 000.0			

Table 1. WHO standards for the maximum concentration in water of various high priority contaminants

2.1. Methods of Water Quality Control and the International System of Standardization of Methods of Control

The system of international standardization of quality control for various materials, including water, is considered to have been born in September 1886, when the first international conference on general standards for methods for testing materials was held in Dresden, Germany. Since that time this system has made steady progress in the interests of the entire world community. In 1926, co-ordination of activity in the field of international standardization led to the creation of the International Association of National Organizations for Standardization (ISA), which functioned up to the beginning of the Second World War. After the Second World War, in 1946, twenty-five countries founded the International Organization for Standardization (ISO), which now has more than 100 participating countries. More than 20,000 scientists, engineers, and administrators from participating countries take part in the development of international standards. The status of specialized agency of the United Nations Organization has been granted to the ISO.

The Technical Committee ISO/TC 147 Water Quality was established in 1971 for development of standards in the field of water quality control, including regulating terms and determinations, sampling procedures, and chemical analytical methods.

In addition to the ISO, various regional organizations have developed international norms and standards on water quality control. The European Committee on Standardization (ENC) unites sixteen countries of Western Europe—predominantly the Member States of the European Community (EC)—and has as its principal task the development of European standards (EN). The largest non-governmental organization in the USA involved with development of standards for water quality control is the American Society for Testing Materials (ASTM). ASTM Standard 19 on Water is also widely used in Canada and in Mexico, which came together with the USA in 1993 as the North American Free Trade Association (NAFTA).

Active participants (P-members)		**Observers (O-members)**	
Australia	Italy	Argentina	Mongolia
Austria	Jamaica	Barbados	Norway
Belgium	Japan	Bulgaria	Portugal
Brazil	Mexico	Columbia	Saudi Arabia
Canada	The Netherlands	Cuba	Singapore
Chile	Poland	Egypt	Tanzania
China	Republic of Korea	Ethiopia	Thailand
Czech Republic	Republic of South Africa	Greece	Trinidad and Tobago
Denmark	Russia	Hong Kong	Tunisia

Finland	Slovakia	Iceland	Ukraine
France	Spain	India	Uruguay
Germany	Sweden	Indonesia	USA
Great Britain	Switzerland	Ireland	Venezuela
Hungary	Turkey	Israel	Vietnam
Iran		Kenya	Yugoslavia
		Korea (KNDR)	Zimbabwe

Table 2. Member countries of Technical Committee ISO/TC 147 Water Quality. Germany provides the Secretariat

It is very important in further discussion of these issues to use the accepted terminology, which has been defined in accordance with the recommendations of the international organizations on standardization of water quality control. Table 3 represents some exposures from the dictionary on water quality accepted by International Standard ISO 6107 (part 8).

Term	**Definition**
Potable water	Fresh water suitable for drinking.
Mineral water	Water in which the concentration of mineral substances is higher than in the usual potable water.
Saline water	Water in which the concentration of salts, in particular of sodium chloride, is higher than in fresh water, but lower than in sea water.
Brine	Water in which the natural or artificial concentration of salts, in particular of sodium chloride, is higher than in sea water.
Rain water	Water formed from atmospheric rainfall, which is as yet free from soil-borne pollutants.
Acid rain water	Rain water with a pH value more than 5.
Ground (soil) water	Water contained in ground formations, which can as a rule be extracted from them
Surface water	Water which flows or accumulates on the earth’s surface.
Downpour water	Surface water forming water flows, resulted from strong downpours.
Relict water	Water held in the pores of rock or sub-surface layers of the earth’s crust, and of the same geological age as the surrounding material, often of poor quality and unsuitable for ordinary use (for example, as potable water or for industrial or agricultural use)..
Tide water	Any sea or river water which is involved in the ebb and flow of tides.
Industrial water	Water utilized in industrial production processes.
Wastewater	Water that is required for production processes amd discharged as a waste product from them.
Mesosaprobic water (α,β)	Polluted water with moderate oxygen concentration that hosts a characteristic set of living species.
Mesotrophic water	Water with a nutrient substance content intermediate between oligotrophic and evtotrophic states.
Gray water	Waste water from domestic baths or showers and kitchen basins without fecal sewage from lavatories.

Black water	Waste water and excrements from lavatories (excluding gray water: see above).

Table 3. Terms and definitions of types of water regulated by the ISO

3. Sources and Types of Polluting Substances in Natural and Wastewater

There are various approaches to the classification of the principal sources and types of substances polluting water. One of most convenient classifications is the one described below, which considers four principal sources of water contamination:

1. Wastewater of animal origin formed as a result of livestock management in agriculture, as well as the municipal wastes emanating from the vital activity of humans. Operational wastes of animal origin, such as discharges from manure heaps, and drainage from animal breeding premises, usually affect the quality of water in nearby small rivers and water reservoirs, and the nearest wells and springs. Household effluent can contaminate rivers and other water courses downstream. Even when water is treated at purification works, some downstream pollution can still occur because not all substances are destroyed by the water treatment process. The polluting substances in domestic water are suspended matter, organic substances including detergents and organophosphorus compounds, inorganic phosphates, bacteria, and occasionally viruses.
2. Industrial wastes, which are very diverse and can contain all known pollutants including heavy metals, acids, alkalis, petroleum products, and radioactive substances, as well as mineral and organic cancerogenes.
3. Surface runoff from municipal and rural areas, containing such pollutants as suspended substances, petroleum products, heavy metals, fertilizers, and pesticides.
4. Incidental pollution from spontaneous non-planned concentrated discharges connected with wars, catastrophes, emergencies, and the incorrect or improper management of industrial or military operations.

An event which caused very serious consequences for the entire planet, and directly or indirectly affected the lives of hundreds of thousands of human beings as a result of radioactive irradiation and environmental contamination, was the accident at the Chernobyl nuclear power plant in the Ukraine in 1986.

Another instance is connected with the high toxicity of modern rocket propellants, in particular, Heptyl (1,1-dimethylhydrazine). There have been very serious consequences for the inhabitants of areas close to launching sites of missiles and space vehicles for civil and military purposes, exacerbated by occasional accidents during start-up.

The incomplete combustion in the atmosphere of the first and second stages of space rockets, including the residual amount of rocket fuel, sometimes up to hundreds and thousands of kilograms, creates the same effect.

-
-
-

Bibliography

American Society for Testing Materials (ASTM). 1994. *ASTM International Directory of Testing Laboratories.* Philadelphia, ASTM. 354 pp. [Handbook on material testing in the USA and NAFTA countries. Standards for water controlling, analytical instruments, and other laboratory equipment are presented.]

Degremont Handbuch, Wasseraufbereitung Abwasserreinigung [in German]. 1974. Wiesbaden–Berlin, BAUVERL. 1090 pp. [One of the best-known fundamental handbooks in the field of water and water treatment. The scientific, technological and engineering aspects of water preparation are presented.]

EEC. 1980. Drinking Water Directive 80/778/EEC No. L229/11 (August 29, 30). Brussels, EEC. [The EC directive on drinking water quality, setting standards accepted by the European Community in 1980. The main water pollutants for priority control in Europe are presented.]

EUROLAB. 1994. *EUROLAB Directory and Handbook: Testing in Europe.* Berlin, Beuth Verlag. 906 pp. [Standardized methods of analytical control, metrological characteristics, instruments for testing, reactants, and other problems of material testing in Europe are described.]

Fomin, G. S. 1995. *Encyclopedic Handbook: Water. Inspection of Chemical, Bacteriological and Radiation Safety According to International Standards* [in Russian]. Moscow, Protector. 624 pp. [Encyclopedic monograph on inspection of chemical, bacteriological, and radiation safety of water according to international standards for water quality.]

Helferich, F. G. 1986. *Ion Exchange: Past, Present, and Future*. NATO ASI, Ser. E, 107, p. 23. [The history and evolution of ion exchange are viewed in the context of the development of science and technology in our time.]

Hernon, B. P.; Zanapalidou, R. H.; Zhang, L.; Sims, K. J.; Siwak, L. R. 1994. Electrodeionization in Power Plant Applications, *Ultrapure Water*, No. 7/8, p. 33. [A new method: electrodeionization for deep desalination and purification of water is described in the article.]

Jackman, A. P.; Powell, R. L. 1991. *Hazardous Waste Treatment Technologies. Biological Treatment, Wet Air Oxidation, Chemical Fixation, Chemical Oxidation.* New Jersey, and Park Ridge, Noyes Publications (NP). 276 pp. [Discusses the problems of reduction and regulation of hazardous wastes, including wastewaters. The scientific basis for modern waste treatment technologies is presented.]

Kardashina, L. F.; Rosental, O. M. 1997. *Chemistry, Technology and Certification of Drinking Water* [in Russian]. Ekaterinburg, URORAN. 224 pp. [The problems of chemistry, technology and certification of drinking water are considered by authors with long-standing experience in water preparation.]

Khamizov, R.; Myasoedov, B.; Novitsky, E.; Vasilevsky, V. et al. 1998. Method for complex processing of sea-water. US Patent No. 5,814,224. [Describes an universal method for complex, discharge-free processing of sea water with production of salts.]

Kulsky L. A.; Strokach, P. P. 1986. *Technology of Natural Water Purification* [in Russian]. Kiev, Vischa Shkola. 352 pp. [One of the fundamental textbooks for institutions of higher education in the former USSR for the specialization on water preparation and wastewater treatment.]

Muraviev, D.; Khamizov, R.; Tikhonov, N. A. 1998. Ion-Exchange Isothermal Supersaturation, *Solvent Extraction and Iron Exchange*. Vol. 16, No. 1, p. 151. [The article describes new progressive ion exchange methods and processes, including the reagent-less "self-sustaining" softening-desalination cyclic processes.]

Randy, J.; Deeny, K.; Ecknoff, T. 1983. *The Activated Sludge Process: Fundamentals of Operation*. Ann Arbor, Michigan, Ann Arbor Science. 350 pp. [Scientific and technological grounds for the biological treatment of wastewaters are described.]

World Health Organization (WHO). 1993. *Guidelines for Drinking Water Quality*, Vol. 1. Geneva, WHO. [Contains basic water quality standards recommended by the World Health Organization (WHO) in 1992.]

Biographical Sketches

Eduard G. Novitsky was born in N. Novgorod, Russia. He was educated at the Moscow Institute of Fine Chemical Technology and obtained his Ph.D. in Chemistry from there in 1967. His fields of work and study are investigations of processes, and design of equipment and installations for membrane and environment protection technologies. Since 1978 he has been Chief of the Department of Membrane and Environmental Protection Technologies at the Russia Research and Design Institute of Chemical Engineering, and since 1991 the General Director of the "Pure Water", J. S. Company. He has published forty-four articles and reports, and holds forty patents from Russia and others countries.

Ruslan Kh. Khamizov was born in Nalchik, Russia, and educated in the Department of Physical Chemistry, Moscow State University, where he obtained his M.Sc. and Ph.D., and the Vernadsky Institute of the Russian Academy of Sciences, Moscow, where he obtained his Dr. of Science (Chemistry). He has worked at the Vernadsky Institute (GEOKHI), Moscow, since 1983, as Research Fellow, Senior Researcher, and since 1998 as Leading Researcher. His subjects are the physical chemistry of sorption and ion-exchange processes, theoretical and experimental study of thermodynamics and kinetics of ion exchange, modeling and computation of mass-transfer processes, and the chemical technology and application of ion-exchange processes for processing natural and industrial solutions. He has published two chapters in monographs and sixty papers in national and international refereed journals, and holds twenty-five patents from Russia, USA, Japan, and other countries.