WATER SUPPLY FOR INDUSTRY

V.V. Shatalov
All-Russian Research Institute of Chemical Technology, Ministry of Atomic Energy, Russian Federation, Russia

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Contents

1. Introduction.
2. Classification of utilized waters and general requirements for water quality used in industry.
3. Thermal power industry.
4. Mining industry.
5. Ferrous metals metallurgy
6. Non-ferrous metals metallurgy
7. Metallurgy of rare, rare-Earth and radioactive metals.
8. Chemical industry.
Glossary
Bibliography

Summary

Requirements for quality of water used for industrial purposes differ significantly. In most manufactures the required water falls within the industrial-drinking class. This relates to the water-consuming industries such as non-ferrous and ferrous metal metallurgy, mining and hydrometallurgy industries, and others. In addition, for special manufacturing plants water of higher quality is used for preparation of final products. Additional requirements are provided for equipment cooling systems, which are water consuming ones. Significant distinctions exist for through-flow and circulating systems. The general ones are the requirements for steam power plants. The specially prepared water should not contain impurities that may cause scale formation. The generally assumed rule for preparation of water used in steam power plants is in regulation of water ion composition, up to complete deionization in the case of high-pressure boilers.

It should be stated that development of water-circulating systems represents a complex engineering and physical and chemical problem the solution of which results in additional wastes in the form of concentrated brines, pulp, etc. However this is the only way to achieve a sharp decrease in water consumption and to maintain free natural water resources. Even stricter requirements are provided for water quality in microelectronic, optical, aeronautical and space industries, etc. Specific requirements exist in food, medical industries and a few other specialized manufacturers.

The common case is that water represents either a reaction or transport medium that is polluted during technological process by products of various chemical or physical and chemical reactions. Therefore repeated water utilization requires the use of specific purification methods because industrial wastewaters are more complex in their composition than the starting water used.

Analysis of water supply systems now in use makes possible to quantify the technical requirements and degree of water resources utilization for every industrial enterprise.

1. Introduction

The twentieth century saw intensive development of industry and agriculture. Novel fields of knowledge and technology appeared (aviation, jet technology, atomic power, biotechnology, etc.). All these changes created enormous demand for water use in various fields. At the same time, the Earth's water resources are limited and water quality varies significantly.

Water resources are created from the following sources:

- seas and oceans – 1380 million km^3 with total mineralization of from 14 to 35 g l^{-1};
- glaciers – from 30 to 50 million km^3 of generally fresh water having salt content of from 100 to 200 mg l^{-1}, rather inaccessible for utilization;
- rivers and lakes – 0.4 million km^3 of fresh (salt content from a few hundreds mg l^{-1} to 1.5-2.0 g l^{-1}) and easily accessible water;
- underground water up to 800 m depth – 4 million km^3, up to 1600 m depth; 4 – 6 million km^3, with salt content ranging from 0.1 mg l^{-3} to strongly mineralized waters.

Thus the main water stock is represented by highly mineralized water, which is unsuitable for drinking water supply, while its use for various purposes requires development of specific technical solutions.

Fresh water represents only a small portion of world water stock. Atmosphere contains from 12 000 to 14 000 m^3 of gaseous water, and riverbeds contain from 2000 to 2500 m^3. This water plays a significant role in human fresh water supplies.

Water in nature is in a state of constant circulation. It evaporates from the surface of the Earth, oceans, rivers and plants and arises in the form of vapors creating clouds, and returns to the surface after condensation in the form of rain and snow.

Underground waters and brines take part in giant processes of mass transfer in the Earth's depths thus promoting chemical processes, salt transfer, etc.

Human activities generally utilize underground and surface waters.

The surface waters include water of open reservoirs—rivers, lakes, water basins. Their composition is defined by climatic, geomorphologic (topography, basin volume), and by anthropogenic factors.

Natural waters (of said type) represent a complex physical and chemical system containing gases, mineral and organic substances in dissolved, colloidal or suspended state. The dissolved state comprises basically mineral salts in the form of cations Ca, Mg, Na, and K, and anions SO_4, CO_3, Cl^-, HCO_3^-. The colloidal state usually comprises various organic substances, iron salts, silicospar, and others; the suspended state comprises clayey, micaceous, calcareous, sandy and other particles.

The underground waters are characterized by significant amounts of mineral salts and low content of organic substances. Conversely, surface waters are characterized by high content of organic substances.

The underground waters include perched water tables, subsoil, interstratum, artesian, interstitial, and karsts waters, the composition of which is determined by formation conditions.

- Perched water tables are waters occurring closest to the Earth's surface (above the subsoil water level) in the area of atmospheric moisture infiltration.
- Subsoil waters are those occurring above the uppermost waterproof layer.
- Interstratum (non-pressure) waters are waters with a free surface, located between two waterproof layers.
- Artesian (pressure) waters occur between two waterproof layers and have no free surface.
- Interstitial waters are those accumulating in rocky fractures.
- Karsts waters occur in big cavities and caverns formed as a result of protracted action of water on rocks.

Waters of perched water tables are usually fresh and contain a lot of organic substances, iron and silicic acid. In the arid regions it quickly becomes highly mineralized. This water is easily polluted due to the absence of waterproof layers. It cannot therefore be regarded as a reliable source of water supply.

Subsoil waters are supplied by rainfall, by subsoil waters and surface reservoirs. This creates significant variability in their composition.

River waters are the main source of industrial water supply and have even greater economic and drinking importance. They depend on feed sources (rain, glaciers, subsoil waters, and so on). The content of suspended substances in rivers varies across a wide range (from 2-6 mg l^{-1} to 10 g l^{-1}), while salt quality is from 30 to 1500 mg l^{-1}. The concentrations are not constant and vary seasonally.

With regard to composition, river waters can be divided into:

- hydrocarbonate;
- sulfate;

- chloride

The content of organic substances also varies significantly (from 2 to 150-200 mg l^{-1}).

Composition of natural waters changes constantly due to processes of oxidation and reduction, blending of waters with different compositions, temperature alterations, ion exchange, precipitation, bacterial self-purification, and other natural factors.

Active natural self-purification factors at present cannot provide satisfactory water quality due to high anthropogenic stress. Therefore, both better physical and chemical treatment of water is required in accordance with users' requirements, or utilization of highly protected sources, mainly artesian ones. All water-consuming industries have various requirements for water quality. The original natural water cannot be used without preliminary treatment by practically all types of water user. The only exception is agricultural irrigation. However in this case there are also certain limitations for concentration and composition of mineral salts. Salts content should not exceed 1.0-1.5 g l^{-1} because otherwise soil salinization may occur due to water evaporation and salt accumulation. The readily soluble salts such as sodium chloride and sulfate and especially sodium carbonate make the water unsuitable for agro-irrigation purposes.

The following basic water preparation processes are general for all types of water utilization:

- preliminary purification from colloidal and suspended particles;
- purification from organic substances;
- water conditioning with regard to ion composition and pH value;
- purification of water from total salts;
- disinfection and deodorization

A variety of methods and equipment is used within the scope of said processes.

Three main approaches may be indicated in development of water supply systems:

- through-flow;
- circulating (closed-type water supply);
- mixed

The first approach is characterized by great expenditure of fresh water and wastewater is fully directed to the hydrographic system. This approach was typical of all manufacturing industry during the first half of the twentieth century and resulted in exhaustion of a number of water sources.

In accord with the Tashkent Declaration of UNO of October 1984, the necessity for industry to switch to circulating water supply systems has been made very clear. These can satisfy all the requirements of complex industrial development as well as ecological requirements.

Different wastewater types should not be mixed because of the difficulty of purifying the total wastewater output. Instead each industry should purify and condition its industrial wastewater to levels that are satisfactory for further utilization in particular technological processes.

Creation of closed-type water supply systems for industrial units allows multiple water utilization in manufacture through local purification along with subsequent re-entry to production process.

Circulating water supply reduces water consumption by a factor of several times and decreases anthropogenic stress. The most advanced plants achieve a water circulation level of up to 95%.

Such systems are characterized by the presence of units for primary water preparation, wastewater purification, conditioning of circulating water, as well as units for processing and storage of solid wastes from water purification (see Figure 1).

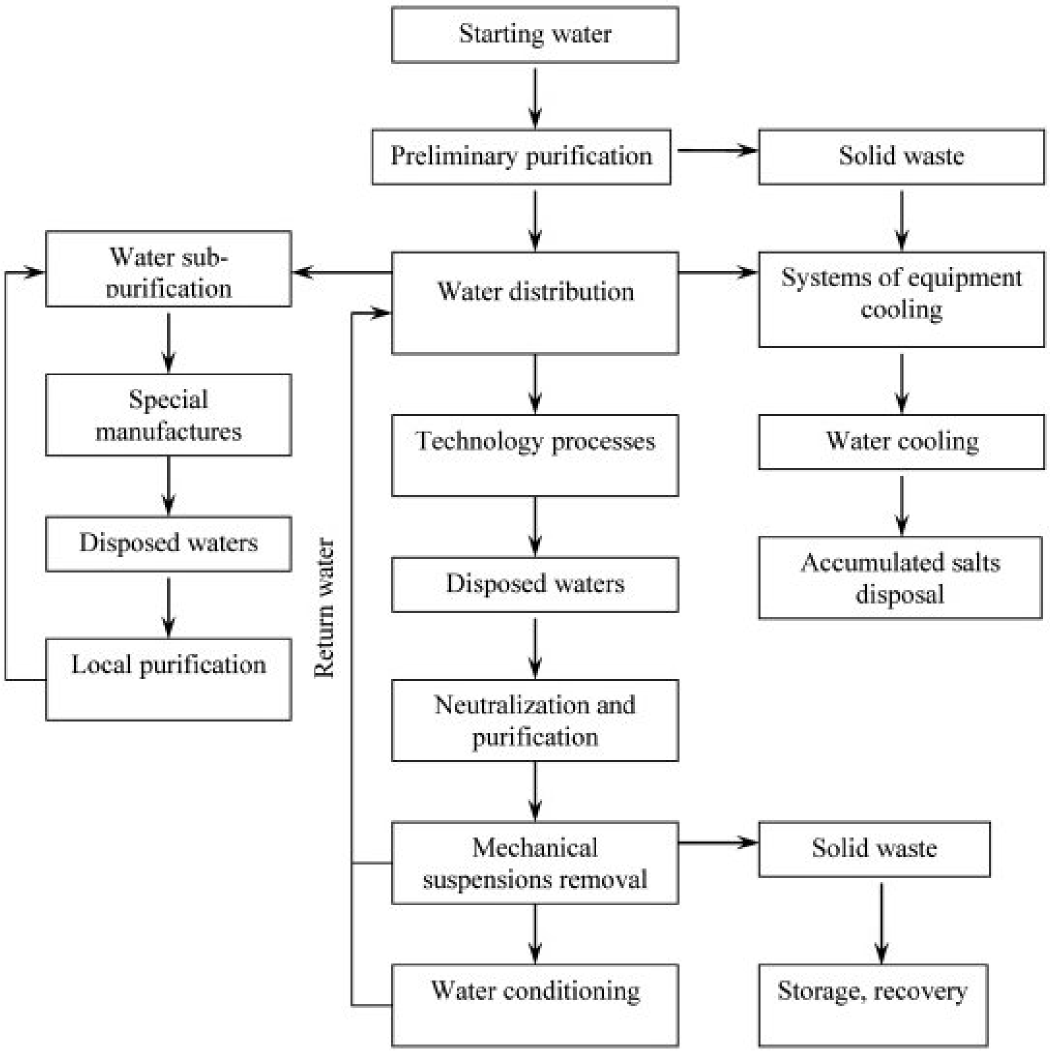

Figure 1. Basic scheme of water supply for industry

As indicated above, the requirements for water quality for different technological purposes vary significantly. However, there are certain general requirements. In most kinds of manufacturing the required water falls within the industrial-drinking class. This relates to water-consuming manufacturing such as non-ferrous and ferrous metal metallurgy, mining and hydrometallurgy, the chemical industry, and others.

Along with the above-mentioned purposes, water of higher quality is used for preparation of final products in some special forms of manufacturing. There are also additional requirements for those equipment cooling systems which consume water.

So, cooling water should not form deposits in pipe and heat exchangers; suspensions of inorganic compounds should be absent, and the presence of organic substances is undesirable. Significant distinctions exist for through-flow and circulating systems. In the first case scale-type deposits are rarely observed because scale in the form of calcium carbonate is removed. In the case of circulating water supply (see Figure 1) the risk of scale formation increases due to a carbon dioxide equilibrium shift when water is cooled by spraying ($Ca^{2+} + HCO_3 \leftrightarrow CaCO_3 + H_2O$).

Steam power plants have fairly general requirements. The specially prepared water should not contain impurities that may cause scale formation. Scale structure and its chemical composition depend on the boiler's operating parameters and on chemical composition of feed water.

The most hazardous in water are salts whose solubility decreases at increased temperatures, i.e. the salts with a negative solubility coefficient ($CaSO_4$; $CaSiO_3$; $CaCO_3$). Salts with positive thermal solubility coefficient precipitate only from concentrated solutions with scale formation in the form of friable slime that is deposited mainly on cooler surfaces. However, presence of such salts decreases the solubility of calcium and magnesium salts, thus increasing risk of scale formation.

Based upon the above-mentioned, the generally assumed rule for preparation of water used in steam power plants is in regulation of water ion composition, up to complete deionization in the case of high-pressure boilers.

It should be stated that development of water-circulating systems represents a complex engineering and physical and chemical problem the solution of which results in additional wastes in the form of concentrated brines, pulp, etc. This is the only way, however, that can lead to a sharp decrease in water consumption and to preserve free natural water resources.

There are even stricter requirements for water quality in microelectronic, optical, aeronautical and space industries, etc. There are specific requirements in the food and medical industries and in certain other forms of manufacturing.

A common case is that water is either a reaction or transport medium that can be polluted during technological process by products of various chemical or physico-chemical reactions. Therefore repeated water utilization requires the use of specific purification methods.

Thus industrial wastewaters are more complex in their composition than the starting water used.

The system of industrial water supply includes:

- preparation of source water for use in technological processes;
- collection and treatment of industrial wastewaters with the aim of purification and further utilization in water circulation systems or their disposal in the open hydrographic network;
- industrial and drinking water supply.

The following definitions are used for qualitative and quantitative characterization of said systems:

a. Irreversible water consumption – amount of water consumed for product production in contact with water per time.
b. Irreversible water loss – loss of water in production due to evaporation, leakage to soil, dropwise loss, etc.
c. Return water – water used in technological process or for cooling of product and equipment, which is purified and cooled, and is again added for the same purposes.
d. Successively used water – water successively used in some production processes or equipment without additional intermediate treatment.
e. Waste water – water used in production and contaminated with industrial products.
f. Water removal – amount of wastewaters removed per time to reservoirs.
g. Water consumption – amount of water used per time for various purposes.

Consideration of existing water supply and water removal systems from the point of view of the above definitions permits technical evaluation for the systems used as well as the scale of water resources utilization for each manufacture.

Technical efficiency of water supply system is estimated by the amount of return water used (P_{re} in %).

$$P_{re} = \frac{Q_{re}}{Q_{re} + Q_{sou} + Q_{fed}} \times 100 \qquad (1)$$

wherein Q_{re} – is amount of return water,
Q_{sou} – amount of water from water supply source,
Q_{fed} – amount of water supplied with the starting feedstuff,
and the greater the P_{re} value, the more efficient is the system used. In the case of highly effective water circulating systems this index is at the level of from 80 to 90%.

Efficiency of utilizing water taken from a water source is estimated by utilization coefficient (K_{ut}) and by the amount of irreversible water consumption and loss (P_{ut} in %).

$$K_{ut} = \frac{Q_{soa} + Q_{fed} + Q_{ww}}{Q_{soa} + Q_{fed}} \leq 1 \quad (2)$$

$$P_{ut} = \frac{Q_{soa} + Q_{fed} - Q_{ww}}{Q_{soa} + Q_{fed} + Q_{suc} + Q_{re}} \times 100 \quad (3)$$

wherein Q_{ww} is amount of wastewater removed to reservoir;
Q_{suc} is amount of water successively utilized in manufacture.

Mean annual water consumption and amount of waste water (m^3/year) in concrete manufacture, is evaluated by the formula:

$$W = N \times Q \quad (4)$$

where W is annual water consumption (m^3 per year), and
N is manufacture amount.

Q is water consumption rate or amount of waste water per production unit; it depends significantly on the amount of water loss in the water supply system, amount of return water used, and also the utilization coefficient. In all cases creation of water circulating systems results in a significant decrease of fresh water consumption as well as of wastewater production.

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Bibliography

Clark V. *Repeated water utilization in industry*. Industrial and Engineering Chemistry, USA, 1962, 27 pp [Some problems of recycling systems' use are discussing].

Frog B.H. and Levchenko A.P. (1996). *Water Preparing*, Moscow: Stroiizdat. [This book contains concise information on the composition of natural waters and methods of quality assessment. The regulations imposed by some water consumers are provided. Modern methods of water preparation. The most important technological layouts and water purification constructions are considered (Russian).]

Gavich I.K. (!985). *Methods of protecting subsoil waters from pollution and exhaustion*. Moscow, Nedra Publisher, 320 pp [Various methods and procedures for underground water protection are considered (Russian).]

Gladkov V.A. (1982). *Enlarged standards for water consumption and water removal for various industry branches*. Moscow, Stroyizdat Publisher, 528 pp [The norms of water consumption and water deriving accepted in Russian practice for various branches of industry are considered (Russian).]

Kastalskii A.A. and Mints D.M. (1962). *Water preparation for drinking and industrial water supply*. Moscow, Visshaya Shkola Publisher, pp.557 [The book contains the technological methods and procedures of water preparing for potable and industrial water supply (Russian).]

Koganovski A.M., Klimenko N.A., Levchenko T.M., Marutovski R.M. and Roza I.G. (1983). *Purification and utilization of wastewaters in industrial water supply*. Moscow, Khimia Publisher, pp.283 [The technological methods and procedures for purification of waste waters and their use for industrial water supply are considered (Russian).]

Kuznetsov Yu.V., Shchebetkovski V.N. and Trusov A.G. (1974). *Fundamentals of water purification from radioactive pollutants*. Moscow, Atomizdat Publisher. [Fundamental and technologic aspects of radioactive pollutants removal are describing (Russian).]

Laskorin B.N. and Barski A.A. (1984). Wasteless technology of mineral feed treatment. Moscow, Nauka Publisher, pp.334 [Various methods and procedures for wasteless mineral feed treatment are considered (Russian).]

Rodionov A.I., Klushin V.N. and Torocheshnikov N.S (1984). *Environment protection technique*. Moscow, Khimia Publisher, pp.512 [The book describes technological methods and procedures applied in the field of environment protection (Russian).]