GUIDELINES FOR POTABLE WATER PURIFICATION

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Keywords: Water purification, Potable water, Unit processes, Water quality, Water treatment, Sedimentation, Flocculation, Filtration, Chlorination, Chemical dosing, Eutrophication, Sand filters, Settling tanks, Organic compounds, Dissolved solids, Aeration, Screening, Treatment plant, Sludge disposal.

Contents

Summary

Water purification for potable water supply involves structures, equipment, and physical and chemical processes arranged in a linear sequence from the raw water input to the finished product water output. The through flow is practically constant, while the undesired constituents are systematically collected, concentrated, separated, and disposed of. Physical processes involved are screening for coarse material removal, settling of suspended materials, aeration, filtration, backwashing, collection, and storage in a reservoir. Chemical processes involved are floc formation, coagulation, pH and hardness control, ion exchange, precipitation of dissolved solids and disinfection. Water treatment plant and processes are generally designed to suit the quality of the particular type of raw or input water and that of the desired treated or product water. They may range from simple filtration and disinfection (chlorination) processes to complex procedures where several chemicals (such as alum or ferric chloride) are first added by flash mixing, dry or liquid feeding to aid coagulation, flocculation before settling, clarification and filtration. Disinfection by chlorination or ozonation is practiced in several ways, also pH control and hardness, color, taste and odor removal. The hydraulic structures and equipment involved in water treatment involve a range of types, including channels and weirs, baffled mixing chambers, slow and rapid sand filters, rotating scrapers and clarifiers, settling tanks and raw and product water reservoirs, pumps, piping and valving, rate controllers, electrical equipment, chemical dosing apparatus and flow and quality measuring devices.

1. Introduction

There is a need among common engineering practitioners, as well as among specialists in other fields, for a simple guide to assist them in evaluating problems relating to water quality and water purification, although there are highly skilled engineers specializing in the design of water purification plants. These guidelines have, therefore, been prepared to meet the above objective.

Nevertheless, users of these guidelines should bear in mind that water purification is an established specialist field of engineering, requiring a depth of insight into the complex physical and chemical reactions involved, as well as experience in the design and operation of treatment plants. Whenever the size and complexity of a project exceeds the level of expertise and experience at which a practitioner can comfortably operate and accept professional responsibility, the assistance of a specialist should be obtained.

The design of a functional water purification plant requires in the first place an understanding of the origin, nature and effects of the impurities in water. Furthermore, if intelligent process selection is to be made, the principles of the various unit processes in water treatment should also be understood. Even so, there are many specialized areas in water treatment which are best left to specialists. Those topics will be indicated as such, and not be discussed in detail in this article.

2. Water Quality

The suitability of water for human consumption is determined by analyzing a sample and comparing its properties with generally accepted standards e.g. as shown in Table 1, taken from the South African Water Quality Guidelines, 1996. Since the designer must have a clear understanding of the meaning of the various parameters being measured, a general discussion on water quality will first be presented.

Substance or characteristic *(mg/L or as indicated)*	Recommended maximum limits for negligible health and/or acceptability risk.	Recommended maximum limits for slight health and/or acceptability risk.
Biological		
Total coliforms (per 100 ml)	5	100
Fecal coliforms (per 100 ml)	0	10
Physical		
Turbidity (turbidity units)	1	5
Color (as Pt)	15	15
Chemical		
pH	6.0 to 9.0	6.0 to 9.0
Conductivity (mS/m)	70	150
Aluminum (as Al)	0.15	0.5

Ammonia (as N)	1	2
Calcium (as Ca)	32	80
Chloride (as Cl)	100	200
Copper (as Cu)	1	3
Fluoride (as F)	1	1.5
Iron (as Fe)	0.1	0.3
Magnesium (as Mg)	30	70
Manganese (as Mn)	0.05	0.1
Nitrate (NO_3) + nitrite (NO_2) (as N)	6	10[a]
Sodium (as Na)	100	200
Sulfate (as SO_4)	200	400
Trihalomethanes (as THMs)	0.1	0.2
Total hardness (as $CaCO_3$)	50 to 100	50 to 100
Zinc (as Zn)	3	5

[a]If nitrate + nitrite (as N) are present in concentrations in excess of ten milligrams per liter, the water is unsuitable for infants under one year of age.

Note: It should be stressed that the above is only an extract of the recommended limits for the macro constituents most commonly found in natural waters. If there is any reason to believe that constituents may be present that may endanger health, or that may meet with consumer resistance, specialist advice should be sought and more comprehensive analyses should be carried out.

Table 1. Guidelines for bacteriological, physical and chemical characteristics for potable water

Water derives its quality in the first instance from substances with which it comes into contact during its passage through air (as small droplets); as well as the ground over which it flows or through which it seeps. It thus dissolves gases from the atmosphere, salts from surrounding rock strata, organic substances from decaying vegetation (which often imparts color), and carries along clay particles which impart turbidity. Water containing the above substances is a suitable environment to sustain ever present microorganisms (mostly bacteria and algae); which in turn may impart further undesirable characteristics to the water, e.g., taste, odor and color, and may also cause disease.

2.1 Microorganisms

Large numbers of microorganisms (bacteria, viruses, algae, fungi and protozoa) are always present in the environment. These organisms are often supplemented by organisms excreted by animals and humans, especially where proper sanitation does not exist. Some of the organisms from human and animal origin may be pathogenic.

Water is an excellent habitat for all microorganisms; especially when the water is enriched with organic material. Microorganisms originating from the intestinal tract of humans and warm-blooded animals normally find the natural environment too hostile to sustain themselves, and die within a few weeks from being excreted. However, if water from a freshly polluted source is consumed, an outbreak of disease may occur.

Since it is impractical to test for all possible pathogens in water, routine tests are directed only at establishing the presence of the so called "indicator organisms," which indicate whether the water has been in contact with fecal material, and therefore may contain pathogens.

The test for coliforms (or total coliforms) is the most common test, and often the only one being performed. Although organisms originating from the human intestinal tract are reflected by the numbers determined by this test, bacteria originating from warm-blooded animals; as well as bacteria that live freely in nature on vegetable matter may also be included. It is, therefore, not a conclusive test, but a positive result immediately casts doubt on the safety of the water (see Table 1 for recommended limits).

Fecal coliforms are secreted by all warm-blooded animals. The test for fecal coliforms is therefore more specific than total coliforms; and since many organisms that may cause disease are common to humans and animals, the presence of fecal coliforms is sufficient reason to regard water as unsafe. The majority of bacteria counted in water samples as fecal coliforms will be *Escherichia coli*. Numbers for fecal coliforms, and for *E. coli*, may for practical purposes be regarded as equivalent (see Table 1 for recommended limits).

The protozoan parasites *Giardia* and *Cryptosporidium*, are environmentally resistant intestinal parasites sometimes found in surface waters, and can cause gastroenteritis in humans when ingested. As a practical guideline, there should be no cysts or oocysts, respectively, of these organisms present in drinking water. Tests for these organisms are sophisticated and time consuming; and are, therefore, not done routinely. The presence of any of the indicator organisms is usually regarded as rendering such water (if untreated) as unacceptable for drinking water. Elimination of these organisms, as well as pathogens (excepting the protozoa) is, however, relatively easily achieved by chlorination. For the removal of protozoan parasites, flocculation followed by filtration, or slow sand filtration is required.

2.2 Physical Characteristics

Physical characteristics are those which are observed by the senses of sight, taste and smell. Consumers are sensitive to physical characteristics and may erroneously perceive water as being unsafe if it exhibits undesirable physical characteristics. The most important physical parameters are suspended matter, turbidity, color, taste and odor.

Suspended matter in natural waters usually consists of leaves, small twigs and small animals such as tadpoles, insect larvae, water fleas, etc. It is understandable that consumers become concerned if these objects are visible in water derived from the distribution system.

Turbidity is very common in inland rivers, and gives water a murky appearance. It is caused by clay particles which are negatively charged, and consequently remain in colloidal suspension. Algal blooms will also give water a green, turbid appearance.

Colored waters are usually found in areas where decaying organic material imparts a brownish color to the water. These waters are usually soft with a low pH, which causes them to be corrosive.

Taste and odor may have various origins. Water from deep boreholes is often devoid of oxygen and has a stuffy smell. Groundwater sometimes contains hydrogen sulfide with its associated bad-egg smell. High mineral content (certain dissolved salts) may impart a strong taste to potable water, particularly when originating from underground sources.

Waters from large shallow impoundments or eutrophied (enriched) sources, may exhibit earthy, fishy or grassy odors, which are accentuated by the addition of chlorine. For potable use, taste and odor should not be objectionable.

Turbidity and color are usually the only two physical characteristics that are routinely determined on a scientific basis, and the results are reported as turbidity units and color units, respectively (see Table 1 for limits).

Physical characteristics are generally of little importance in terms of health risks, but are the first to cause complaints from consumers because concentrations in excess of recommended limits are easily detectable. It is, therefore, psychologically desirable to ensure that water is physically attractive.

2.3 Chemical Constituents

Since water is an excellent solvent, it will dissolve a large variety of chemical compounds. When the chemical compounds exceed certain concentrations in the water, various undesirable characteristics may develop. The chemical compounds also generally establish the pH value of the water.

There are routine analytical procedures available, whereby the elements and compounds comprising the macro- and micro-chemical constituents may be measured.

With respect to the salinity of water, it has become customary to measure conductivity (in mS/m), which reflects the ability of the water ability to conduct electrical current, and hence gives an indication of the concentration of mineral salts in solution. Recommended limits for some of the chemical constituents are given in Table 1.

2.4 Trace Organics

With the ever increasing use of pesticides and herbicides, as well as the discharge of sophisticated organic compounds into wastewaters, the level of trace organics in the environment is always increasing. These organic compounds, when subjected to chlorine, are oxidized to form what is generally known as trihalomethanes (THMs), which are suspected of being carcinogenic in high concentrations. Recommended limits for allowable concentrations of these compounds or their precursors, are given in Table 1.

Measuring THMs requires sophisticated equipment. It is, therefore, only be done if there are strong indicators that these substances may be present, e.g., if the water source contains large amounts of chlorinated sewage effluent.

Excesses of chemical constituents may be manifested in various ways. Water may taste salty or brackish if the salt concentration (especially of chlorides) is high, and stomach upsets may result. High concentrations of calcium and magnesium cause hardness. Iron and manganese will cause brown or black stains on white surfaces. Excessive fluoride will cause staining of teeth, and heavy metals such as cadmium and chromium may cause chronic poisoning. Low pH values will cause corrosion of metals and concrete. Water over-saturated with calcium carbonate will cause pipelines to become clogged by calcium carbonate deposits.

Some of the chemical characteristics of water may be changed fairly easily, e.g., the pH by the addition of an acid or a base. Other characteristics, e.g., a high salt content, will require desalination, which is a sophisticated and expensive process (see chapter *Desalination*).

3. Overview of Unit Processes in Water Purification

The forces of nature may be utilized in various ways to improve the quality and remove the undesirable characteristics of water.

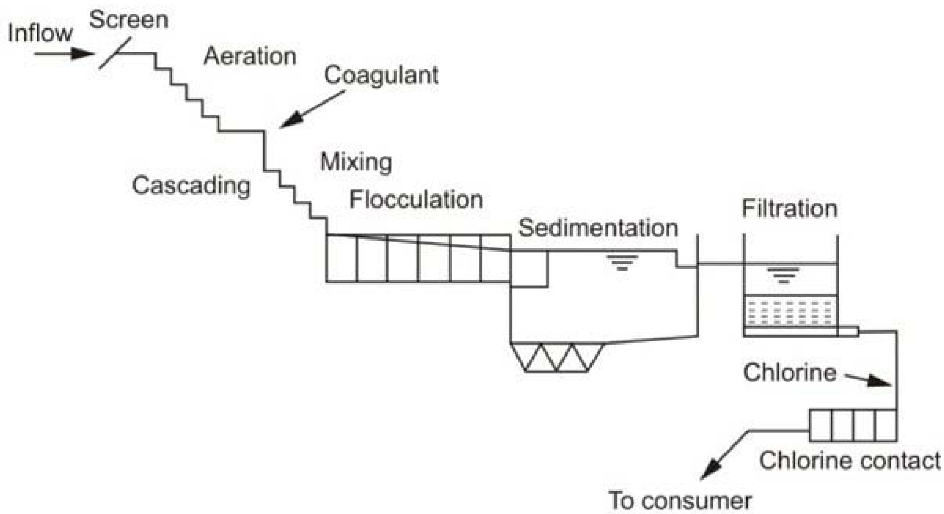

Figure 1. Diagrammatic layout of typical water purification plant

Purification processes employing these forces can be of a physical, chemical or biological nature. The extent to which specific processes will be used will depend on the nature of the foreign material to be removed, as well as on the skills of the operator. The layout of a typical water purification works is shown diagrammatically in Figure 1. Not all the unit processes will necessarily be used in every application.

3.1 Screening

It is customary to use a screen at the point of water abstraction from a surface source to prevent the ingress of twigs, leaves, fish, frogs, etc., into the purification works. Where applicable, a simple sieve with five to fifteen millimeter apertures, and a flow-through area giving a velocity not exceeding 0.5 m/s will normally suffice.

3.2 Aeration

Water drawn from the bottom of a reservoir or from deep bored wells sometimes has a stuffy smell. A simple cascade where the water falls through a total distance of one to two meters may normally be sufficient to dissipate such offending odors. Odors caused by hydrogen sulfide will, however, not be removed in this way, and require exposure to the atmosphere for at least 48 hours in an open reservoir. In the case of the tastes associated with algal blooms in surface waters, no degree of aeration or exposure will be of any use, and adsorption on activated carbon will be required. This is a specialized field.

3.3 Flocculation

Flocculation is intended to remove turbidity and color from water. It comprises chemical reactions (coagulation) taking place under favorable physical conditions (suitable vorticity or turbulence) and at the optimum pH for the particular water.

It is often necessary to perform flocculation tests to establish optimum concentrations of coagulants, as well as suitable vorticity for the particular water, before attempting a design. It is customary to express vorticity in terms of the velocity gradient or *G* value (radians/second), in actual fact expressible as meters per second per meter (in a direction at right angles to the flow).

Coagulation (which is the chemical part of flocculation) is brought about by the addition of a coagulant, usually a ferric or aluminum compound, to the water. These compounds release trivalent cations (Fe^{3+}, Al^{3+}) into the water, which react with the ever present hydroxyl ions (OH^-), as well as with the colloidal clay particles and ions containing color, both of which are also negatively charged, to form small flocs.

The most commonly used coagulants: aluminum sulfate, ferric chloride and ferric sulfate, decrease the pH value of the water. Addition of an alkali, usually lime (calcium hydroxide) is sometimes necessary to establish the optimum pH value.

Another important group of coagulants termed the “poly-electrolytes” or cationic polymers, are long-chain organic compounds capable of coalescing the negatively charged particles in the water to flocs capable of being settled out.

The reactions of some of these compounds, which are specially formulated by commercial companies, and only known by their proprietary names, are pH independent, and therefore, ideally suitable for small works where pH control is often erratic.

Cationic polymers are sometimes used in small concentrations as flocculating aids, in conjunction with alum or ferric compounds, in which capacity they tend to reduce the required concentrations of the metal ions, and also help to form stronger flocs.

3.3.1 Chemical Dosing

The first step in flocculation is chemical dosing. Chemical dosing should take place in such a way that the chemical is dispersed instantaneously through the entire water mass.

Lime, $Ca(OH)_2$ is the only chemical normally dosed in the form of a dry powder, because it is so insoluble that a solution cannot be made up. It is stored in a bin with a hopper bottom from which the powder is extracted at a predetermined rate, typically with a screw tube of variable speed, or a rotating table with adjustable blade, see Figures 2 and 3. The dry powder is dropped into a suspension mixer, as shown in Figure 4, from which it is discharged into the water.

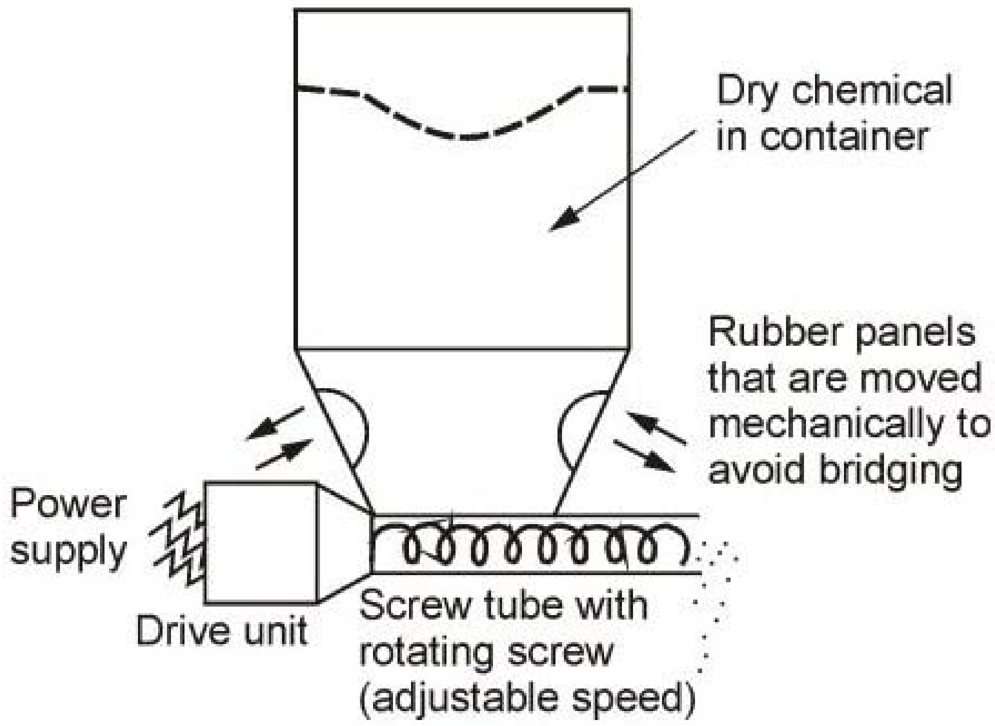

Figure 2. Screw tube lime feeder

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Biographical Sketch

Willie Malan graduated in 1957 from the University of Stellenbosch with a B.Sc. and a B.Eng., and in 1969 with an M.Sc.(Eng.) from the University of Pretoria. He is a registered Professional Engineer in South Africa and a Member of the South African Institute of Civil Engineers and the Water Institute of South Africa. His professional career encompasses the following:1958–1959, Lecturer in Applied Mathematics, University of Stellenbosch; 1960–1961, Construction Engineer, Department of Water Affairs; 1962–1968, Research Officer, National Institute of Water Research, South Africa; 1969–1971, Specialist Consulting Engineer (Water Care); 1971–1998, Senior Lecturer in Civil Engineering, University of Stellenbosch; and up to the present, part-time Specialist Consulting Engineer. He was involved with major project planning for the Cape Town Metropolitan Area Waste Water Conveyance, Treatment and Disposal, and with similar projects (water and waste water treatment works) for

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