Professional paper

Water pre-treatment process in food industry

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ABSTRACT

A successful food and beverage processing operation needs a stable high water quality supply and the appropriate treatment of wastewater. On many occasions the finished product is not just a result of the raw material, but caused by changes in feed water quality. Besides water quality, the most important requirement is reasonable cost for the feed water. There are several fresh water sources, which are chosen upon several factors. The most appropriate action is as less treatment as possible. The regulations are stringent and defined in detail. The objective of this review is to provide a brief explanation of the water pre-treatment methods available in food processing, emphasizing on clean technologies, such as membrane technologies, aeration and ion exchange.

KEY WORDS:

Drinking water, Food industry, Pre-treatment, Membrane.

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INTRODUCTION

Safe water and hygienic sanitation coverage is still low, especially in rural areas. Fresh water resources, especially those of high quality, are becoming scarce because of population growth and urbanisation [1]. The availability of good quality water and in high quantities is vital for food safety and production. Water can contaminate food: protozoa, viruses and in some cases even pathogens may be spread from contaminated water to the food. Such water is not potable and drinking or using such water in food preparation might lead to widespread acute and chronic illness.

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Water influences the structure and taste of food and its receptiveness to spoilage. In any case, the presence of organic matter, colour, taste, and odour is unacceptable in water to be used in food and beverage processing operations, and must be removed.

Waste from food processing is similar to the food itself. More concentrated wastewaters come from processes where food is transformed in some way, such as the blanching the vegetables or pickling the meat [2]. The volume and contamination level of wastewater from food processing depends on the type of process and the size and age of the plant, as well as the season. Wastewaters are mainly high in organic matter. Biological oxygen demand (BOD) can be as high as 10,000 mg/L in wastewaters from breweries and distilleries. Wastewaters from farms are high in dissolved solids (up to 3,000 mg/L).

Water recycling within an industrial plant is normally integrated in to the industrial process. Food processing approaches based on good science will be needed in order to determine the synergic effects of hybrid technologies [3].

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The use of recycled water will need the development of enzymes, the use of particle science, and other new technologies. Particularly good explanations regarding the microbial and chemical hazards of how new treating systems work will enable them to be applied in practice. Crucial public and professional acceptance is research on identifying appropriate indicators of microbial levels and determining human health risks. The most sustainable alternative has to be discussed, not only from the viewpoints of municipal companies, local authorities, local residents and environmental organization, but also, in each case, public opinion should be considered substantially.

PROCESS WATER

Process water is used in washing and sanitizing raw materials, process and ancillary equipment, and greenhouse. Water has to meet the safe drinking water standards. It has to be clear, colour-, taste- and odourless, or with other words free of contaminants affecting our sense organs.

The constraints of the beverage and food industries have to be fully understood and to be able to make suitable process water. The standards and compliance with the quality specifications of the finished product must be ensured. Many enterprises provide innovative solutions for water supply requirements and their system has to ensure reliable supply of high-quality water and its control. Very important is also the system design, installation and maintenance.

Water reuse within industry can be fully exploited, except for food and pharmaceutical applications.

PRE-TREATMENT PROCESSES

It is necessary to create water pre-treatment coupled with the principles of a single method, in order to enhance aesthetic acceptability, and the removal of toxic or health-hazard materials. Detailed description and advances are described in the following chapters.

We always believed that groundwater are reliable resource, but recent researches have proved that the water is contaminated by numerous organic chemicals, such as soluble organic substances (SOC), persistent chlorinated biphenyls (PCB), heavy metals, etc. Such contaminants are found along surface water supplies, and among them and in many rivers. These substances are mostly tasteless and odourless.

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Often a variation in quality characteristics regarding a finished product is due to the quality of the water used in the process, and not a result of the raw materials or the process. Processors must know with certainty that the water supply meets the following requirements:

- Reliable–sufficient redundancy so a supply within an acceptable pressure range is assured regardless of drought or other adverse weather influences.
- Consistent quality.
- Consistently meeting of applicable water quality standards.
- Reasonable cost.

A quality public water supply should require little, if any, treatment prior to many of its uses. Public supplies are treated and tested to ensure they meet established safe drinking water standards for microbiological, inorganic chemicals, organic chemicals and radiological quality requirements.

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Water should be tested regularly to assure compliance. Water used for cooking or added directly to the product must be potable and must be of sufficient quality not to degrade product quality. This includes being free of dissolved minerals that make water excessively hard or affect taste.

Removal of organic matter

The most widely used systems are the conventional methods, such as precipitation, coagulation and flocculation, sedimentation and filtration. Dispersed, suspended, and colloidal particles producing turbidity and water colour, cannot be removed sufficiently by the normal sedimentation process. Adding a coagulant, mixing, and stirring the water cause the formation of settleable particles. These flocks are large enough to settle rapidly under the influence of gravity, and may be removed from suspension by filtration. In chemical precipitation units, coagulation and flocculation aids are usually added to facilitate the formation of large agglomerated particles. These are simpler to remove from the water. The precipitants, as well as other suspended solids, often have similar or neutral surface charges that repel one another. Coagulants, bounding to the particles in the wastewater stream, essentially convert the surface charges; as a result, opposite charges form between the particles, causing them to agglomerate. The use of inorganic metal salts (normally Al/Fe (III) salts) for coagulation is very well established in the field of water treatment. Flocculant aids, typically anionic polymers, are added to further enhance the agglomeration of the particles. The degree of clarification obtained depends on the quantity of the chemicals used, mixing times, and process control. One of the major disadvantages of coagulation is the handling and disposal of the sludge resulting from chemical precipitation.

Volatile organic compounds (VOC) are removed by aeration. The air diffuses into the water. The equilibrium between Φ_{VOC} in solution phase and c_{VOC} in the gas phase, is established according to Henry's law (Equation 1).

$$K_H = \Phi_{VOC}/c_{VOC} \quad (1)$$

K_H – Henry's Law Constant.

At constant temperature and pressure, the concentration of a substance in the vapour phase is proportional to its concentration in the aqueous phase.

Soap and detergent residues have to be carefully removed, in order not to produce scum and curd.

Organic contaminants are also removed by biological processes. Bacteria adapted to in-site specific conditions are able to degrade organic contaminants. As the contaminants are degraded, the adapted bacteria grow. The increased biomass is a waste that must be managed.

Colour, odour, and taste removal

When iron or manganese is present in water, both metals are oxidized (by dissolved oxygen) and, consequently, coloured precipitates are formed, not only in water but also on equipment, vessels, pipes and fixtures. A common treatment is ion exchange and the use of iron filters, mostly filled with catalytic materials, which are very efficient for iron and manganese removal, and require fewer chemicals for regeneration.

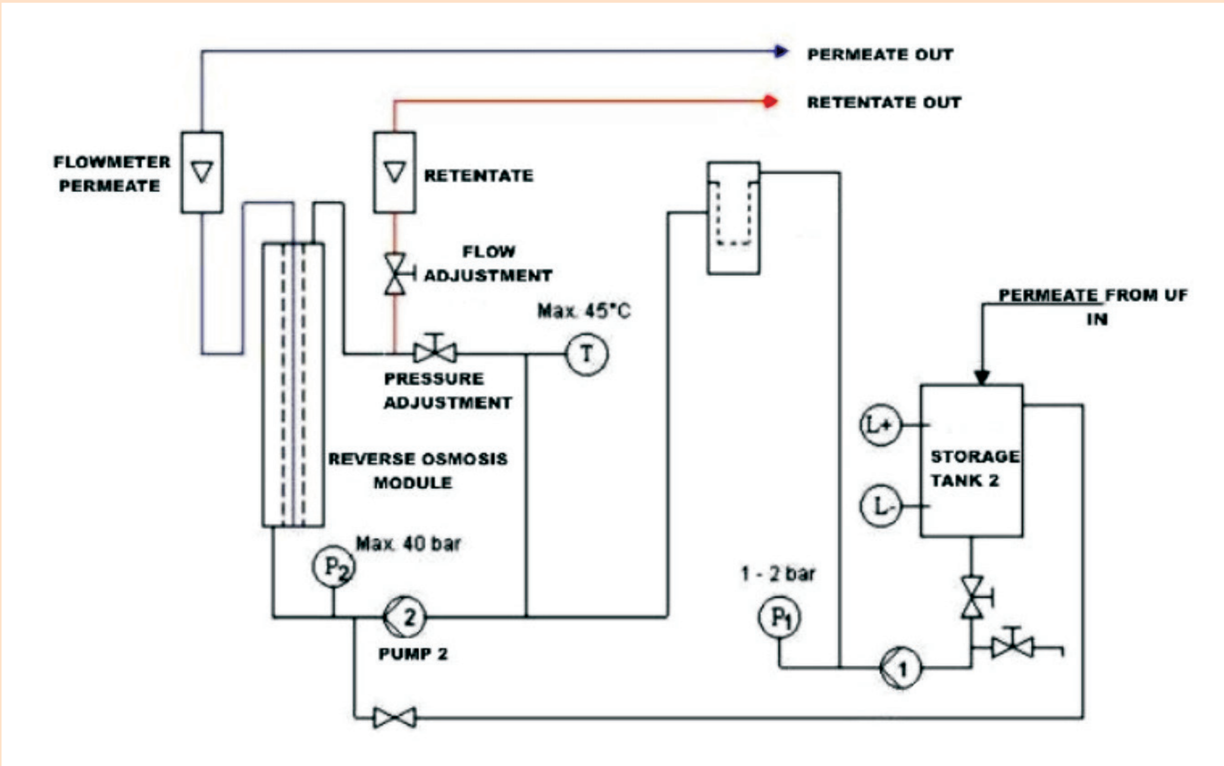
Adsorption on granular (GAC) and power activated carbon (PAC) is the most commonly used conventional methods and the most successful adsorbents used for organic matter as well as for colour, odour and taste removal. Activated carbon is prepared by activation at a high temperature of 800 °C – 900 °C, from a variety of carbonaceous materials. Before carbonization, the raw material is pulverised, blended with a binder and palletised under pressure to give 5 mm – 10 mm spheres. After pyrolysis at 500 °C, thermal activation follows in the presence of CO_2, which produces a complex of macro- and micro pores. A GAC surface area ranging from 750 m^2/g – 1500 m^2/g allows organic substances to be adsorbed from water. The adsorption depends on the nature of the adsorbent, surface area and pore structure, particle size, and surface chemistry. Increasing temperature decreases adsorption. Adsorption is a three step process:

- transport of the adsorbate from the solution to the outer surface of the adsorbent particle (diffusion controlled);
- transport from the outer surface to interior sites by diffusion within the macro- and micro-pores;
- adsorption at a site in the micro – pore – this is the most rapid step.

The overall rate is determined by the slowest step.

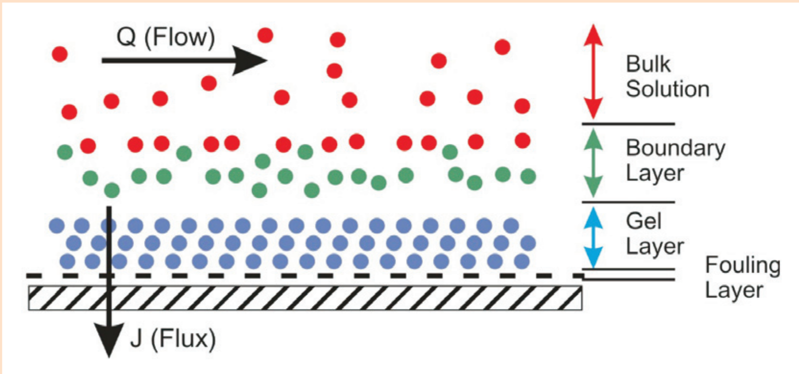
Reverse osmosis equipment can remove taste, colour and odour from water. It can remove all known micro-organisms and most other health contaminants. The reverse osmosis unit is shown in the Figure 1.

Figure 1:
Reverse osmosis unit
(Author: M. Simonič).



Membrane processes are characterised by the fact that the feed stream is divided into two streams: into the retentate or concentrate, and the permeate one. In all membrane processes separation is achieved by a membrane, which can be considered as a permselective barrier existing between two homogeneous phases. Transport through the membrane takes place when a driving force is applied to the components in the feed. In most membrane processes the driving force is a pressure difference or a concentration difference across the membrane. High pressure on the source side forces the water to reverse the natural osmotic process, with a semi permeable membrane permitting the passage of water while rejecting most of the other contaminants. This specific process is called ion exclusion, in which ions form a barrier for substances at a membrane's surface except for the water molecules. Hydrodynamic flux controlling factors are presented in the Figure 2.

Figure 2:
Hydrodynamic Controlling Factors of Flux (Author: M. Simonič).



Degasification

Dissolved gases should be carefully controlled, as they can affect those products and processes in which the water is used. The removal of dissolved gases is accomplished by vacuum degasification column or aeration using another gas (nitrogen). Over the last few years membrane contactors have become commercially available. A membrane contactor utilises the same laws that govern the operation of conventional degasification columns.

Membrane contactors are shell and tube devices with micro-porous hydrophobic hollow fibres as presented on the Figure 3. Since water will not pass through the pores, the membrane's surface acts as an inert support that allows water to come into direct contact with the gas phase without dispersion. The partial pressure of the gas can be adjusted to control the amount of gas that will dissolve into water. Since the membrane contactor contains very small-diameter fibres, the interface between the gas and liquid phases becomes very high. This concept can reduce the size of a device. This newly patented design incorporates hollow fibre fabric array that is wound around a central distribution tube with a central resin baffle. Thus allows greater flow capacity.

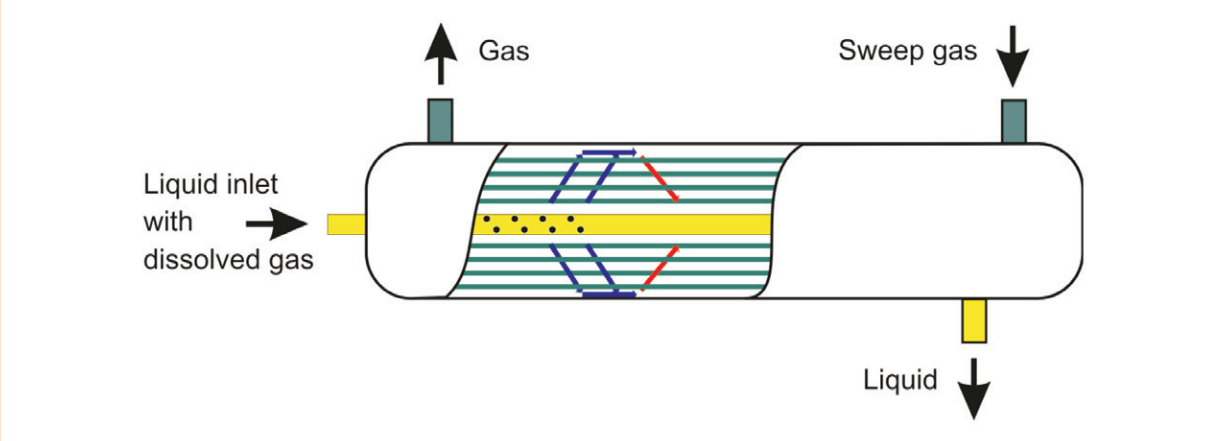


Figure 3:
The membrane contactor [5].

Water desalination

The selection of a water supply should be based on available quantity, quality, and cost of development, and investigating usable fresh surface water and groundwater thoroughly, prior to consideration of sources requiring desalination. When fresh water sources do not exist, saline water sources should be considered. The most commonly used parameter to differentiate between saline water qualities is total dissolved solids (TDS). Total dissolved solids are defined as the sum of the dissolved organic materials and the inorganic salts. Fresh waters contain less than 1,000 mg/L of total dissolved solids. Brackish water contains 1,000 mg/L – 20,000 mg/L of total dissolved solids. Sea water usually contains at least 20,000 mg/L of total dissolved solids. If well – water contains between 500 mg/L and 3000 mg/L of TDS and electricity is inexpensive, electro dialysis reversal or high – flux reverse osmosis is indicated. Without adequate pre-treatment, desalination facilities have reduced life-times, high maintenance cost and produced shorter periods of operation. Solids can be removed by a modern up-flow sand filter with a continuously cleaned filter bed, making shutdowns for backwashing of the filter bed unnecessary [4]. Also, reservoirs for wash water and sludge liquor can be spared.

The feed is introduced at the top of the filter and flows downward through an opening between the feed pipe and airlift housing. The feed is introduced into the bed through a series of feed radials which are open at the bottom. As the influent flows upward through the moving sand bed, the solids are removed. The filtrate exits at the top of the filter.

Simultaneously, the sand bed, along with the accumulated solids, is drawn downward into the airlift pipe, which is located in the centre of the filter. The sand and the solids are transported through the airlift into a washer/separator with a central reject compartment. As the sand falls through the washer, which consists of several concentric stages, a small amount of filtered water passes upward, washing away the dirt, while allowing the heavier, coarser sand to fall through to the bed. By setting

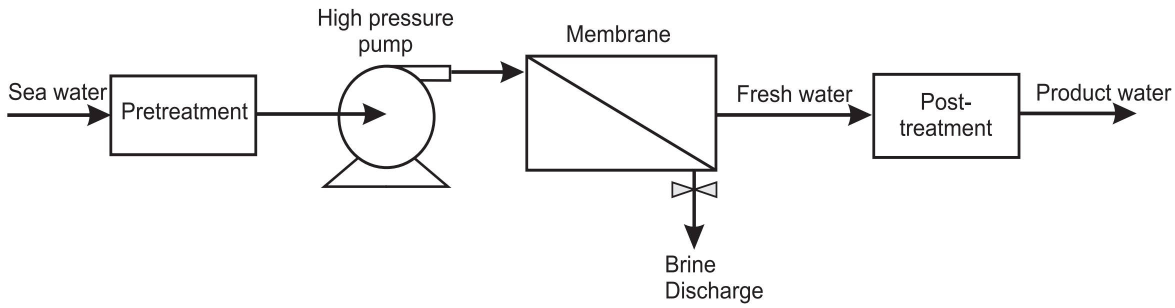


Figure 4:
Desalination process [6].

the reject weir at a lower level than the filtrate weir, a steady stream of wash water is assured. Continuous reject exits near the top of the filter. Optimal adjustment of the wash water volume is possible by varying the weir height.

The production of saline water usually requires a significantly larger quantity of saline feed than the quantity of potable water produced. After desalination of sea water more than 70 % of the intake may be rejected as brine, and only up to 30 % for product water, while by desalination of non sea or brackish water only 5 percent of the feed stream is rejected as brine [6].

Reverse osmosis has become the state of the art for water desalination (Figure 4). It is applied for the production of drinking and industrial process water from brackish water sources. Spirally wound elements are indispensable for power plants. Very high operating costs are still mostly connected to high energy consumption. However, the product water costs have dropped from 1 USD/m^3 in the early nineties to 0.55 USD/m^3 nowadays.

During membrane **desalination** operations at high recovery ratios, the solubility limits of gypsum and calcite exceed saturation levels, leading to crystallization on membrane's surfaces. The surface blockage of the scale results in permeate flux decline, reducing the efficiency of the process, and increasing operational costs.

In reverse osmosis elements, **colloidal pollution** can seriously diminish performance by decreasing productivity. An early sign of this pollutant is usually an increasing pressure gradient. The sources of this pollution in feed water can vary greatly. They are usually bacteria, clay, and iron corrosion products. Those chemical products used during pre-treatment may also cause fouling of the membranes. The best available technique for the determination of feed water fouling potential by colloids is the Modified Fouling Index (MFI) measurement. This is an important type of measurement that takes place prior to the design of a pre-treatment system. This measurement must be done regularly when the reverse osmosis (RO) system is put to use.

The number of micro-organisms in the surface water, in the feed water and in the concentrate can provide us with valuable information on the

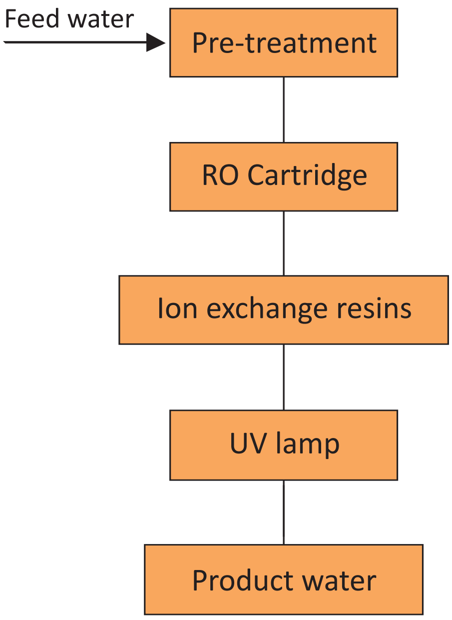


Figure 5:
The Milli-Q ultra pure water system [7].

degree of water contamination (bio-fouling). The types and concentration of nutrients present in the feed water are factors that determine bio film growth. Despite the fact that there are several investigators that determine the growth of bio films, it has not been fully researched yet.

Often the use of Millipore water is required, especially in the pharmaceutical industry. The principle is that, prior to RO membrane, some pre-treatment processes are needed, such as micro-filter and activated carbon filter for free chlorine and colloids removal from tap water (Figure 5). Ion exchange resins are continuously regenerated by means of an electrical current applied within the module itself. It provides the advantage of using resins of good quality all the time and needs no chemical regeneration that would deteriorate the resin beads. Two resins are placed between anion- and cation-permeable membranes, in a purifying channel each, and a concentrating channel is placed between them.

The anode electrode chamber is placed on one side of the first purifying channel, and the cathode electrode chamber on the other side of the second purifying channel.

Scaling

Hard water usually needs to be softened to be acceptable for food and beverage processing. Hard water causes toughening of vegetable skin during blanching and canning. Softening is mostly required to avoid scale. The tendency to develop scale ($CaCO_3$) during the treatment can be approximated by calculating either the Langelier Saturation Index (LSI) or Ryzner index (RI) [8,9].

The most common softening processes are precipitation, cation exchange, and demineralisation. Ion exchange resins are well suited for cation removal, because they have high capacities for cations, the resins are stable and readily regenerated, they are independent of temperature and are very suitable for huge systems in the food industries. Most exchange material is manufactured by polymerisation of styrene and divinylbenzene. It has to be chemically activated to perform the ion exchange. Each active group has a fixed electrical charge, which is free to exchange with other ions of the same charge. The ion exchange material has to be insoluble, resistant to fracture, and of uniform dimensions. Strong acid cation resins are formed by treating the beads with a strong acid (H_2SO_4 or HCl).

Resin has a greater affinity to ions with higher valences – a predominance of high valence ions can cause a higher rate of reaction. Increasing temperature can speed up chemical reactions. The exchange reaction is a diffusion process, and the diffusion rate of the ion on the exchange site has some effect. The strength of the exchange site, whether it is strongly or weakly acidic or basic, affects the reaction rate, too. The selection of an appropriate resin for specific application is determined by feed water analyses, and the desired effluent quality.

Disinfection

The easiest way to destroy micro-organisms is to add 5 mg/L – 8 mg/L chlorine solution, lower concentration is used in a product to prevent off flavours. A less suitable method is pasteurization, especially because of processing costs (high fuel requirements). It is to boil water rigorously at 115 °C for 10 – 15 minutes. Very powerful disinfection is achieved by using ozone. It is prepared by electrical discharge in air or oxygen at high voltage. The half – life of ozone in water is 40 minutes at pH 7.6 and 14.6 °C.

Exposure to a sphere of water, 120 mm in diameter, to a point source of 254 nm radiation for 5 seconds is adequate for disinfection of bacteria and some other organisms. The radiation dose rate I_o (W/(m^2.s)) and the dose is $I_o \cdot t$ (W/m^2).

Groundwater contains only a few micro-organisms, while surface water contains a large number of many different kinds of micro-organisms. Microbial growth can be controlled by physical methods including the use of heat, low temperatures, desiccation, osmotic pressure, filtration, and radiation. Chemical agents include several groups of substances that destroy or limit microbiological growth. Factors affecting micro-organisms are temperature, pH, oxygen and water pollution. Human pathogens in water supplies usually come from contamination of water with faecal material. Many pathogens that leave the body through the faeces – many bacteria, viruses, and some protozoa can be present.

Water is usually tested for faecal contamination by isolating *Escherichia coli* from a water sample. *E. coli* is called an indicator organism because it is a natural inhabitant of the human digestive tract. Its presence indicates that the water is contaminated with faecal material.

Purification procedures for human drinking water are determined by the degree of purity of the water at its source. Water from deep wells or from reservoirs fed by clean mountain streams requires very little treatment to make it safe to drink. In contrast, water from rivers that contain industrial and animal waste and even sewage from upstream towns, require extensive treatment before it is safe to drink. Some micro-organisms may remain unaffected by chlorine treatment. For example the Legionella species not only survive but multiplies in storage tanks and other water systems.

Worldwide, the most common bacterial diseases transmitted through water are caused by *Shigella*, *Salmonella*, enterotoxigenic *Esherichia coli*, *Campylobacter jejuni*, and *Vibrio cholere*. Viral infections include hepatitis A, Rotavirus and Norwalk-like virus. Common parasites include *Giardia lamblia*, *Cryptosporidium*, and *Entamoeba histolytica*. The first water-borne outbreak caused by cryptosporiridium occured in Texas in 1985.

A more serious problem is that several pathogens are more resistant to disinfection than coli forms. Chemically – disinfected water samples that are free from coli formed bacteria are often contaminated with enteric viruses. The cysts of *Giardia lamblia* and *Cryptosporidium* are so resistant to chlorination that eliminating them with this method is impractical. Mechanical methods, such as filtration and flocculation, are necessary to remove colloidal particles because the micro-organisms are mostly trapped by surface adsorption in the sand beds.

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Routine examination of water and wastewater for pathogenic micro-organisms is not recommended, because very well-equipped laboratories with well-trained personnel are needed.

Examination of routine bacteriological samples cannot be regarded as providing complete or final information concerning sanitary conditions surrounding the source of any particular sample. The results of examination using a single sample from a given source must be considered inadequate. The final evolution must be based on examining a series of samples collected over a known and protracted period of time. The most effective microbiological monitoring of water source is to simply, rapidly, and inexpensively determine the presence of indicator bacteria: Coliform group, Faecal coliform bacteria, Heterotrophic plate count (HPC).

Final evolution must be based on examining a series of samples collected over a known and protracted period of time.

CONCLUSION

The described processes, recommendations for use and removal of contaminants are gathered in the Table 1. Whilst the economic benefits are the central point of management, more emphasize should be given to equally consider the environmental and social aspects in future decision-making processes. Long time ago some authors [10] pointed out that economic benefits are significant for companies which are looking for more effective solutions to pollution through conservation-oriented technologies by reducing water use and waste generation, because in food plants pollution prevention is more economical than pre-treatment.

Table 1:
Processes, recommendations for use and types of contaminants separated.

Process	Recommendation for use	Contaminants removal
Aeration	Degassing.	VOC, NH_3, CH_4, CO_2
Adsorption	Aromatics removal, colour, odour, and taste removal, dechlorination.	Phenols, BTEX, THM, aromatics, H_2S, pesticide
Cation/Anion exchange	Softening, denitrification	Calcium, magnesium, iron, manganesse, nitrate, arsenic
Chlorine/Chlor-dioxide	Disinfection	Bacteria, protozoa
Coagulation/ Sedimentation	Water purification	NOM
Membrane Contactor	Gas separation	CO_2, O_2, AOX
Membrane UF	RO pre-treatment, Disinfection	NOM, bacteria, protozoa
Membrane RO	Desalination	TDS, Hg, pesticide
UV	Disinfection	Bacteria, viruses

REFERENCES

[1] Kirby RM, Bartram J and Carr R. Water in food production and processing: quantity and quality concerns, Food Control 2003; 14: 283-299.

[2] Gray NF. Biology of wastewater treatment. Dublin: Imperial College press, 2004: 53.

[3] Allende A, Tomas-Barberan FA and Gil MI, Minimal processing for healthy traditional foods, Trends in Food Science&Tech 2006; 17: 513-319.

[4] Voutchkov N. Tapping the Ocean for Fresh Water in Carlsbad: http://www.waterandwastewater.com/www_services/news_center/publish/article_00778.shtml (20. 6. 2006).

[5] Liqui-Cel. Overview brochure: http://www.liqui-cel.com/product-information (20. 7. 2006).

[6] Water desalination: technical manual. Headquarters, No TM 5-813-8. Department of the army, USA, 1986.

[7] Millipore AFS 60 and AFS 60D analysers feed systems (1997) USA, Millipore: http://www.millipore.com/publications.nsf/docs/pf224 (22. 7. 2006).

[8] Tchobanoglous G, Burton FL and Stensel HD. Wastewater engineering, Treatment and reuse. New York: McGraw-Hill, 2003: 528-532.

[9] Lenntech Scaling and Antiscalants: http://www.lenntech.com/antiscalants.htm (20.7. 2006).

[10] Carawan RE. In food plants pollution prevention is more economical than pre-treatment, Waste reduction-pollution prevention: Progress and prospects within North Carolina. Raleigh: 1988.