Water treatment with emphasis to magnetic separation methods

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Abstract. One of the most important natural resources is the water. Surface and ground waters are the main sources and there are several differences between them. We need not only water in adequate quantities to cover the human necessities but also we have to develop systems that deliver a good quality of water. The majority of human uses require fresh water. However, in water sources there are several undesirable contaminants. A conventional water treatment includes the processes, flocculation, coagulation, sedimentation, filtration and disinfection. In some cases, a serious issue that we have to deal with is the hardness of water. In this paper we study the effect of magnetic fields on the removal of calcium carbonate which is responsible for the water hardness.

INTRODUCTION

The water is a vital element for life. Man can survive without food for more than a month but it is impossible to live without water for more than one week. He needs water to survive. Every cell of the human body requires water as nourishment and to remove wastes. The lack of water reduces the amount of blood, causes many problems in health.

The role of water in human culture and civilization is well documented all over the world. It is very significant all people to have access to this resource, as water is used for drinking, preparing food, cleaning, bathing, irrigating landscapes etc.

Water is considered as a renewable resource. In our days the world's supply of groundwater is steadily decreasing due to the expanding human population and its competition for the water. Even the climate change is a significant factor that affects the available quantities of water. The strong connection between the climate and hydrologic cycle is studied intensively.

The agriculture, industrial, household, recreational and environmental activities are the main uses of water. All these uses require fresh water. All over the world, a large percent of about 70 % of water use is estimated that is for irrigation in agriculture.

The major drinking water sources include ground water, surface water, atmospheric water generation, rain water harvesting, fog collection and sea water.

Surface water and groundwater are both important sources. Approximately 98 percent of liquid fresh water exists as groundwater, much of it occurs very deep in the Earth. This makes pumping very expensive, preventing the full development and use of all groundwater resources.

The accessibility to safe drinking water are of major concern throughout the world. The drinking water must be free of chemical substances and organisms, when it is used for human

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consumption. The increase use of chemicals in most countries has deteriorated the water quality.

Each source of water has a unique set of contaminants. The quality of ground and surface water is not the same In most cases the ground water in contrast with surface water is microbially safe and chemically stable in the absence of direct contamination. For example groundwater contains pesticide chemicals and nitrate while surface water stores most bacteria and other microorganisms. These contaminants may be shared between the two sources due to their interconnectedness. Their contamination could be varied depending on the source of pollutant. There is no water source free from undesirable contaminants.

First of all, the water supplier has the responsibility to set the first barriers in protection of the water resources in order to provide drinking water of high quality. With this action that leads in decreasing of the contamination the degree of required treatment is reduced and the operation costs of a water treatment plant are lower. The factors that influence the quality of raw water are both natural and human. The first category includes wildlife, topography, geology, vegetation and the second refers mainly to wastewater discharges, urban and agricultural runoff, as agrochemicals and livestock or recreational use [1].

The next step is the water treatment process including coagulation, flocculation, sedimentation, filtration and disinfection. These processes are used for the removal of particles and microorganisms. The microorganisms may be pathogenic and capable to cause disease or mortality to human population. Chlorination is the most common disinfection process while chloramination, chlorine dioxide application ozonation and ultraviolet irradiation are also used [1].

DRINKING WATER

Drinking water is the water that is safe enough to be consumed by humans or used with low risk of immediate or long term harm. Another definition of water is potable. This word comes from the latin potabilis, meaning drinkable.

The occurrence of undesirable contaminants in raw water affect the human health and influence the water quality. The removal of them is necessary and obligatory in most of the cases and especially crucial when the water source is surface.

The quality parameters set for drinking water described by drinking water quality standards. In most developed countries, the water supplied to households, commerce and industry meets these standards.

All developed countries specify quality standards of drinking water to ensure the consumption of safe water In European Union drew up the Council Directive 98/83/EC on the quality of water intended for human consumption, adopted by the Council on 3 November 1998. This Directive provides a sound basis for both the consumers throughout the EU and the suppliers of drinking water [2].

In USA, the Environmental Protection Agency (EPA) sets standards that, when combined with protecting ground water and surface water, are critical to ensuring safe drinking water. EPA works with its regional offices, states, tribes and its many partners to protect public health through implementing the Safe Drinking Water Act [3].

World Health Organization (WHO) produces international norms on water quality and human health in the form of guidelines that are used as the basis for regulation and standard setting, in developing and developed countries world-wide [4]. These guidelines are the international reference point for standards setting and drinking-water safety.

WATER POLLUTION

There is evidence of widespread contamination of water resources. It isn't known exactly the health effects from the long term exposure to the contaminants that enter in the water supply system. It is noticed that all contaminants do not pose a threat to human health. When the pollutants enter water sources their concentrations dilute and are reduced by biological degradation, filtration, and adsorption to soil. Some chemicals are very stable in the environment, such as the chlorinated hydrocarbons. Some of these can accumulate in living organisms and are not readily metabolized and excreted. The most effective way of reducing contaminants in drinking water is by controlling it at the source.

Iron, manganese, barium, fluoride, hydrogen sulfide, and salt may be present in water resources at undesirable levels. Bacteria from sewage, and animal wastes are a common problem. Another issue is the high level contamination form nitrate-nitrogen levels in agriculture areas.

In order to have unpolluted water man treated it from the ancient years. The first methods of water treatment were recorded as early as 4000 B.C. In ancient Greek and India (Sanskrit) the filtering, the exposing to sunlight, the boiling and the straining were applied to improve the taste and odor of drinking water. The Egyptians after 1500 BC, using the chemical alum, discovered the coagulation method that caused the settling out of suspended particles. Another significant process for removing particles from water was filtration. This method was established during the 1700s. In Europe the filtration with sand was used by the early 1800s.This method was established as a successful way of removing particles from water and widely adopted in Europe during the nineteenth century. During the middle of nineteenth century was discovered a cholera epidemic spread through water and then the chlorination method was applied to purify the water. In this period worries about the quality of drinking water focused on pathogens in public water supply systems. The chlorination played a significant role to reduce the waterborne disease outbreaks in the early 1900s, as it was clear that filtration did not remove all the bacteria from public-use water. Today, the most effective treatment techniques for protecting water supplies from harmful microbes are filtration and chlorination [5,6].

However during chlorination, chlorine reacts with natural organic materials and forms a large category of organic compounds, named haloforms that may pose carcinogenic or mutagenic properties. A characteristic example is trihalomethane (THM) formation [7].

WATER TREATMENT PROCESSES

Drinking water treatment technologies and purification techniques have been used and continuously developed over the ages, to protect public health from pathogens and chemicals [6].

Coagulation, flocculation, sedimentation, filtration and disinfection are the most commonly applied water treatment processes. They used worldwide in the water treatment industry, from the end of nineteenth century, before the distribution of drinking water to consumers [8].

Each process is used for different purpose [1,9,10,]:

Coagulation promotes the interaction of small particles to form larger particles. The process refers to coagulant addition (i.e. addition of a substance that will form the hydrolysis products that cause coagulation), particle destabilization and interparticle collisions. Chemical coagulation has indirect impacts on the efficiency of disinfection process.

- Flocculation is the physical process of producing interparticle contacts that lead to the formation of large particles.

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The goal of coagulation and flocculation is to remove fine suspended particles. These particles can attract and hold bacteria and viruses to their surface. The percentage of removal for bacteria and viruses is 99.9 and 99, respectively. They can also remove some of the organic matter that gathers as water travels across the land, from raindrop to surface water. However, they cannot remove full taste and odor.

- Sedimentation is a solid–liquid separation process, in which particles settle under the force of gravity.
- Filtration can act as a consistent and effective barrier for microbial pathogens and in some cases may be the only treatment barrier. It occurs as the water passes through a substance that helps remove even smaller particles. Filters can be made of layers of sand, gravel and charcoal.

However in many cases this treatment is not sufficient. For example, adsorption and oxidation may be required if undesirable impurities contained in the water. These are two additional treatment processes, where adsorption is a type of chemical filtration while oxidation can offer water disinfection and can destroy taste, odor, algal toxins, pesticides and other soluble contaminants. Oxidation can also remove iron and manganese [9].

These processes are very common all around the world and their purpose is to remove turbidity and contaminants from water and to improve and protect water quality. The characteristics of the water, the types of water quality problems, the cost of different treatments processes and some other factors define the alternative treatments that would be chosen. A great challenge involving technological development is the need to develop technology that is suitable, applicable, and sustainable [6].

THE ROLE OF MAGNETIC MATERIALS TO WATER PURIFICATION

Water purification using physical methods such as magnetic separation, have drawn the attention of the scientific community in the past few decades. The formation of scale deposits by natural waters can significally limit or completely block the water flow in pipes or boilers and heat exchangers, resulting in heat transfer efficiency reduction and leading progressively in equipment damage. Huge amounts of energy are wasted therefore causing severe technical and economic problems in the industry.

Experimental results of a magnetic field on the precipitation process of calcium carbonate scale from a hard water have been reported [11]. Because a magnetic field is able to disturb the double ionic layer surrounding the colloidal particles and their zero potential, would also tend to reduce the nucleation rate and to accelerate the crystal growth. Experimentally the nucleation time was identified from the variations of the pH and the Ca^{++} concentration. It was shown that the magnetic treatment increases the total amount of precipitate and the effect depends on the solution pH, the flow rate and the duration of the treatment.

In order to better understand and explain how a magnetic field influences nucleation, another study [12] using X-ray diffraction and electron microscopy techniques for the characterization of the carbonates formed by heating water has shown that drawing water through a static magnetic field of approximately 0.1 T increases the aragonite/calcite ratio in the deposit.

A valuable review paper [13] presents and explains several aspects on water purification techniques using magnetic assistance. According to this paper based on the difference in adoption of physical process, magnetically assisted water purification can be classified in several categories, as follows. In the direct purification method, there is no carrier magnetic component added. The magnetic field helps in inducing crystallization and then a magnetic filter is used to remove salt ions and to prevent them to enter the pipelines. Seeding method following by a high gradient magnetic separation device is also one of the older methods used for water purification. A coagulant cation under proper chemical conditions yields an insoluble precipitate with positive susceptibility under applied magnetic field. This property is used to trap the coagulant with contaminant on a magnetic filtration assembly. Magnetic ion exchange resins method were introduced for the removal of organic matter from ambient raw water, because the ion exchange resin beads contain a magnetized component within their structure which allows the beads to act as individual magnets and form agglomerates. Finally in the combined application method, as the name indicates, magnetic separation techniques are additionally employed in order to further improve the separation efficiency after the initial treatment of the water with electrolytic or catalytic reactions.

Magnetism helps in water purification by influencing the physical properties of the water contaminants. The method exploits the difference in behavior of particles in magnetic fields. This property is characterized by a dimensionless variable called magnetic susceptibility which is denoted as χ. The specific magnetic susceptibility is then defined as $\chi_m = \chi / \rho$, where ρ is the density of the material. Materials which repelled from the magnetic field have negative values of magnetic susceptibility and are called diamagnetics, while particles attracted towards greater intensity of the magnetics field are called paramagnetics.

Magnetics separation is based on the principal that the force acting on a particle is given by the equation $F = \mu_0 \chi_m m H \nabla H$

Therefore the component of the force acting on a particle in magnetic field in the x-axis is $F_x = \mu_0 \chi_m m H \dfrac{\partial H}{\partial x}$, where $\mu_0 = 4\pi 10^{-7} Wb / A.m$ denotes the magnetic permeability of vacuum, H is the magnetic field intensity, *m* the mass of the particle and $\dfrac{\partial H}{\partial x}$ is the field gradient.

From this equation it is obvious that the collection of particles is strongly depends on the creation of these large magnetic field gradients, as well as on the particle size and its magnetic properties. This can be achieved by placing magnetically susceptible wires inside an electromagnet. These wires dehomogenize the magnetic field producing large gradients around the wires that attract magnetic particles to their surfaces and tram them there. Consequently with the adoption of this technique, the formation of calcium carbonate particles expected in the bulk of the scaling water preventing them to precipitate on the walls of the distribution pipes.

Another crucial aspect is the strength of the magnetic field that we are going to employ in a magnetic separator. In cases where the pollutant are solids, separators based on permanent magnets are the most appropriate choice, while in cases where the amount of pollutants is low, high intensity magnetic field is required and the superconducting magnets should be used. A superconducting magnet is an electromagnet with coils made out of superconducting wires. During its operation is has to cooled down to cryogenic temperatures. The major advantage of using superconducting magnets, is basically their reduced operation costs, which is due to the fact that basically there are no losses of power to ohmic resistances. Finally an important application of superconducting magnets is the removal of the radio toxic hazard of plutonium which is form compounds with paramagnetic properties.

CONCLUSIONS

The clean drinking water is a crucial matter. Population growth, changes in habits and our daily needs have created a tremendous demand for potable water that meets the quality

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standards. The conventional processes including coagulation, flocculation, sedimentation, filtration and disinfection reduce the concentration of particulate matter and provide water that does not contain pathogenic contaminants.

One of the major problems is the water hardness. Waters with high hardness treated to remove the calcium and magnesium salts. The principle of water purification using magnetic separation methods has been analyzed and applied in the case of calcium carbonate particles removal. The efficiency of the process can be evaluated by measuring the ionic calcium concentrations before and immediately after the water treatment. Despite the fact that this is a very promising and low cost operation method, several other parameters like the geometry of the device separator, the velocity of the water flow, the temperature of the water which can affect the solubility and the precipitation of the calcium carbonate and the pH of the water, have to be studied more thoroughly in order to maximize the efficiency of the water treatment process.

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