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Technologies for the Removal of Dissolved Inorganic Substances Contained in Wastewater

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Abstract – The purpose of this paper is to outline the necessity of advanced urban wastewater, which contain residual substances that are scarcely removed or practically unaltered through means of traditional bio-mechanical treatment steps (detergents, phosphates, nitrogen based compounds, persistent organic compounds, pesticides, diverse chemical compounds), which have a devastating impact upon the environment.

The paper presents four technological schemes, for ultra filtration procedures and reverse osmosis within a single step, as well as for phosphorous removal by utilizing lime, all of which are applied toward removing inorganic dissolved substances contained in wastewater.

Keywords – chemical precipitation, ultra filtration, reverse osmosis, electro dialysis

I. INTRODUCTION

The exploitation of wastewater treatment plants and sludge management, in the context of human activities, especially regarding the environment, must be seen in the light of optimizing these activities towards environmental protection.

Associating the notions of durable exploitation and quality of life must have the purpose of "ensuring contemporary needs without compromising the ability of future generations to do so as well".

The economical, social and environmental systems that comprise the community, offering a healthy market, a prosperous lifestyle, within a significant percent for all residents in a community, now and in the future, are strongly intertwined and cannot be considered separately, when the realization of effective durability is the desired goal.

A robust medium, which is sustained by the coherent needs and applicable judicial standards, operationally viable technologies, as well as an acceptable cultural medium, show that durability is closely tied to the consumption of renewable resources to an extent at least equal to their natural regeneration.

When the total sum of natural resources is used faster than it can be naturally regenerated, the unsustainability state emerges, in which the long term degradation of the environment is an expected outcome, which in turn implies the environment's inability to sustain human life.

Although the concept of durability has theoretically clear and precise directions, the major issue is their practical implementation, which has proven to be a difficult task, for the solutions need to be especially conceived for each area of activity, as well as for the specific social, economic and technological levels of each implied community. Therefore, in the case of wastewater treatment plant management and the management of their byproducts, the issue of these systems is meeting the durability requirements in regard to the management of the sludge that results from the treatment process [1].

The sludge management systems are often inefficient and unsustainable, especially because a single treatment process is unable to encompass all of the three aspects; the environment, economic and social, which are necessary to fulfill the needs of durable development. A change in regards to more durable procedures must be promoted through an integrated approach, which must include, among other things, new and innovative procedures in regards to planning and management; promoting the self-sustainability of energetic systems or of the systems, with a reduced energy consumption; raising the level of reusable materials that result from wastewater treatment processes for different useful purposes etc.

A strategy regarding the collection and reuse of useful residual products would become a main concern. Traditional recycling options would as well, such as the direct use of wastewater in agriculture, which are progressively limited and, in some cases, prohibited, which leads, as well, toward searching for new solutions.

The development of new, correct and durable, sludge management procedures should mainly focus toward reducing the quantity of sludge that is to be eliminated by means of:

- applying the reuse options, which are aimed at recovering energy or useful products, instead of simple disposal;
- developing integrated systems, which are self sufficient from an energetic point of view;
- producing, while ensuring safety regulations and environmental protection, materials that result from sludge exploitation (natural fertilizer);
- implementing adequate operational systems for local conditions, in order of achieving durable development while ensuring environmental protection.

II. METHODS OF INORGANIC DISSOLVED SUBSTANCE REMOVAL

The operations and procedures applied in the removal of inorganic dissolved substances are:

- chemical precipitation;
- ion exchangers;
- ultra filtration;
- reverse osmosis;
- electrolysis.

2.1. Chemical precipitation

The chemical precipitation of phosphorous from wastewater is currently accompanied by alum, lime or ferric salts and organic polymers. Simultaneously, the addition of these chemical reagents for phosphorous removal also removes many inorganic ions, mainly heavy metals [1], [2], [3].

In cases where industrial wastewater is treated alongside domestic wastewater, the addition of chemical reagents within the primary sedimentary installations may be necessary when on-site pretreatment measures are not efficient.

Anaerobic fermentation for sludge stabilization is not possible when using the chemical precipitation procedure, due to the high level of toxicity of the precipitated heavy metals. One of the disadvantages of chemical precipitation is that currently it manifests through a net increase in dissolved substance concentration in the treated water. Another disadvantage is the necessity of processing a large quantity of sludge, which, at recycling, can contain toxic compounds that can be difficult to treat or recover [1], [8].

2.2. Ion exchangers

The ion exchangers procedure boasts the widest use in domestic wastewater softening, where sodium ions, from a cationic exchange resin, exchanges the calcium and magnesium ions in the treated domestic wastewater, softening it. For the removal of the total dissolved substances, both anionic as well as cationic exchange resins must be used. Wastewater is first passed through a cationic exchanger, where positive charged ions are replaced by hydrogen ions. The effluent of the cationic exchanger is then passed through an anionic exchange resin where the anions are replaced by hydroxide ions. In this way, the dissolved substances are replaced through hydrogen and hydroxide ions, which react, forming water molecules.

Ion exchangers are usually of columns filled in down flow current type. Wastewater enters under pressure though the top of the column descends through the resin bed and is removed at the bottom. When the resin capacity is diminished, the column is washed counter-current, thus removing captured substances and then is regenerated. The cationic exchange resin is regenerated by means of a powerful acid, such as sulfuric or hydrochloric acid. For regenerating the anionic resin, sodium hydroxide is used.

Demineralization through ion exchangers can take place in separate exchange columns placed in succession, or both resin types can be combined within a single reactor. The water input speed can vary between $0,2 \div 0,4 \text{ m}^3/\text{m}^2, \text{min}$. The thickness of the layer varies between $0,75 \div 2,0 \text{ m}$. At high suspension concentration levels in the influent, the ion exchange layer can be clogged, leading to increase in pressure drop and system malfunction. The residual organic substance contained in the biological effluent can determine resin grouting. Before demineralization through ion exchangers, realizing certain chemical treatment and decantation is necessary. Not all dissolved ions are removed in equal measure; each resin exchange resin is characterized through a certain selectivity, so that at the end of the sequence, some dissolved ions are only partially removed [4], [5].

In reuse applications, only a certain quantity of the wastewater flow is treated through means of ion exchangers, after which the treated water is mixed with water that was not treated with ions, making the process of reducing dissolved substances at acceptable concentrations possible.



2.3. Ultra filtration

Ultra filtration systems are systems of porous membranes that are operated by means of pressure, which retain colloidal and dissolved matter. These systems differ from reverse osmosis systems through a relatively reduced operating pressure, usually under 1.034 kN/m^2 .

Ultra filtration is normally used to retain colloidal matter and macromolecules with a molecular weight over 5.000. Applications of ultra filtration include the retention of oils within the water and turbidity reduction.

2.4. Reverse osmosis (hyper filtration)

This is a process in which water is separated from dissolved salts in the mixture through filtration by means of a semi permeable membrane at a pressure greater than osmotic pressure at which wastewater salts are dissolved (*fig. 2*).

2.5. Electrolysis

In the process of electrolysis, ionic components of a mixture are separated by means of a selective semi permeable ion membrane.

The application of an electric potential between to electrodes produces an electric current that passes through the mixture, producing a migration of the cations toward the negative electrode and of the anions toward the positive electrode. Due to the alternation of the cation permeable and anion permeable membrane spaces, concentrated or diluted salt cells are formed.

Wastewater is pumped through membranes that are separated by spacers and assembled in stacks. Wastewater is normally retained within a single stage for approximately $0\div 20 \text{ s}$.

Dissolved salt removal from wastewater varies with: wastewater temperature, electric current level, ion types and quantities, membrane permselectivity, wastewater debit and the number and configuration of the stages.

This procedure can run either continuously or sequentially. The units can be arranged either in parallel, in order to ensure an adequate hydraulic capacity, or in succession, to ensure the needed demineralization level.

Wash water, generally 10% of the supply debit, is necessary for continuous cleaning of the membranes. One percent of the concentrated debit is recirculated in order to maintain certain debits and pressures that are approximately equal on both sides of each membrane. Sulfuric acid is added in the concentrated debit in order to maintain a low pH level.

The problems associated with electrolysis in raising wastewater quality include chemical precipitation of salts with low solubility on the membrane's surface and the membrane's clogging due to colloidal organic matter from the wastewater treatment plant's effluent. In order to reduce membrane issues, charcoal pretreatment may be required, possibly preceded by chemical precipitation and some forms of multiple medium filtration [1], [6].

III. CONTRIBUTIONS

The purpose of this paper is the presentation of efficient technological schemes aimed at the improvement of urban wastewater, utilizing ultra filtration and reverse osmosis.

Recent research shows that the effluent of an ultra filtration system is a convenient supply source for the reverse osmosis system. Ultra filtration was also suggested as a functioning unit for phosphorous removal.

With the available membranes and equipment, operational pressure varies from atmospheric pressure toward 6.900 kN/m^2 . The advantage of reverse osmosis is that it reduces dissolved organic substances which are less selectively removed than in other demineralization techniques.

The main drawbacks are high operational costs and limited operational experience in urban wastewater treatment. The base components of a reverse osmosis unit are the membranes, the support structure for the membranes, a safety recipient and a high pressure pump.

As membrane materials, cellulose acetate and nylon have been used. Four types of support structures have been used for the membranes: snailwrapp, tubular and diverse configurations of filters with gaps. The snail support type is the most appropriate for urban wastewater [1].

Figure 1 shows a technological scheme for improving urban wastewater quality by means of ultra filtration and reverse osmosis [1].

Reverse osmosis units can be placed be it in parallel, to ensure adequate hydraulic capacity, or in succession, to ensure the required demineralization level.

In order to achieve efficient operational parameters of the reverse osmosis system, a superior quality influent is required. The systems membranes can be clogged and damaged by the colloidal matter present in the influent. Therefore, the pretreatment of the secondary effluent is required by means of clarification through chemical reagents and multiple stage filtration, or multiple stage filtration and ultra filtration.

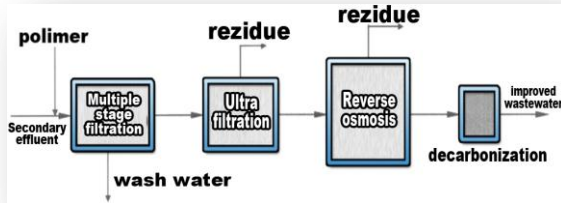


Figure 1. Technological scheme for the ultra filtration procedure

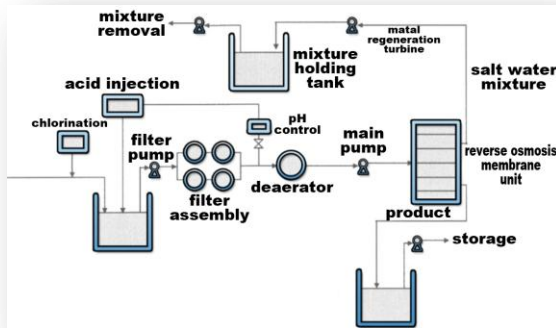


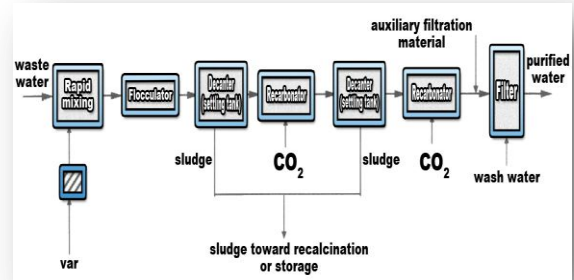
Figure 2. Technological scheme for single step reverse osmosis procedure

Sometimes, iron and manganese removal is also necessary in order to lower the cleaning potential. The pH of the influent must be brought to 4,0÷7,5 in order to inhibit stone formation. Periodic chemical cleaning of the membrane unit's elements (usually once a month) is necessary for reconditioning the membrane's flux.

Regarding the removal of phosphorous and suspended residue loads, the decanted effluent has to be filtered through multiple stages, but the excess calcium must be limited in order to avoid cementing the filters.

Figure 3 presents the main methods of wastewater treatment with lime [1]. In the settling tank of the first step of two-stage purification process (see fig. 3,b) sufficient lime is added in order to maintain the pH at the value of 11 for the precipitation of soluble phosphorous as apatite (basic calcium phosphate).

a) Single stage system



b) Two-stage system

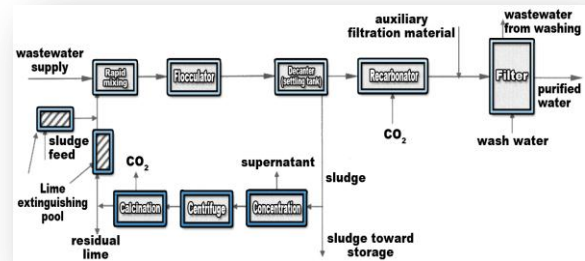


Figure 3. Technological schemes for phosphorous removal utilizing lime

The procedure through which nitrogen, contained in raw or purified wastewater, is transformed into nitrates is called biological nitrification.

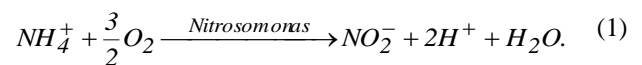
Nitrification is an autotrophic process (i.e. the required energy for bacteria growth, especially autotrophic chemo-synthesized bacteria, derives from oxidized N compounds, mainly ammonia).

Unlike heterotrophic bacteria, nitrifiers use CO₂ (inorganic C) and not organic C for synthesizing new cells [1].

Ammonia nitrification is a two stage process which involves two types of microorganisms; nitrosomonas and nitrobacteria.

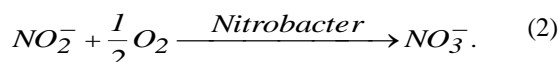
In the first stage, ammonia is transformed into nitrites:

Stage I:



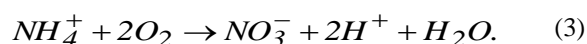
In the second stage, nitrites are transformed into nitrates:

Stage II:



(1) and (2) are energy producing reactions. Nitrosomonas and Nitrobacteria consume the energy derived from these reactions in order to survive and maintain cellular growth.

The total energetic reaction is:



Regarding the issues of judicious exploitation of wastewater treatment plants and implicitly of the obtained results of said exploitation, a combined approach would serve future needs.

A worldwide overview of the actual state and prospects of the future provide additional information in regards to process evolutions and the byproducts of wastewater exploitation.

IV. CONCLUSIONS

The clear conclusion that emerges from this paper is the necessity of advanced urban wastewater treatment, due to the residual substances found within them, which are scarcely removed or practically unchanged through classic bio-mechanical steps (detergents, phosphates, nitrogen based compounds, inorganic salts, persistent organic compounds, pesticides, diverse chemical compounds), which have a tremendous negative impact on the environment.

The removal of these resilient substances requires the insertion of a treatment technology which completes classic treatment, in order to ensure environmental and health protection, resulting in a quality water that can serve diverse purposes. This technology is called tertiary, advanced or *improved*.

Biological nitrification/denitrification is the best method for nitrogen retention because:

- it has a high efficiency in nitrogen reduction;
- it boasts high operational stability and feasibility;
- the process is relatively easy to supervise;
- it requires small areas of land to undertake;
- it has moderate cost.

Nitrogen reduction through means of biological nitrification/denitrification is a two stage process. In the first stage, ammonia is converted into nitrate (NO_3^-), within an aerobic environment the first stage thus being the nitrification stage.

In the second stage, the nitrate is further converted into gaseous nitrogen (the denitrification stage). Along with the improvement of scientific knowledge of pollutants present in wastewater, as well as the availability an extensive informational database due to environment monitoring studies, the requirements for the quality of the treated effluent that is discharged in the emissary have become more strict. In most cases, severe conditions are imposed regarding the removal of organic substances, suspensions, nutrients and specific toxic compounds, conditions which cannot be respected by means of only classic conventional wastewater treatment. In areas where the emissary takes over the wastewater treatment plant's effluent, meaning they are also sources of freshwater supply for downstream use, the requirements imposed by quality standards are certainly extremely severe.

Evaluating the impact of a wastewater treatment plant over the community and over the environment must be looked at through the prism of the three areas that must be taken into consideration when elaborating or putting into practice a durable approach on residual wastewater treatment: the environment, economy and society. The monitoring of different wastewater treatment situations is imposed worldwide.

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