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Investigating the Feasibility of Removing Nitrogen and Phosphorus from Gray Water in Effluent Treatment to Reuse Water

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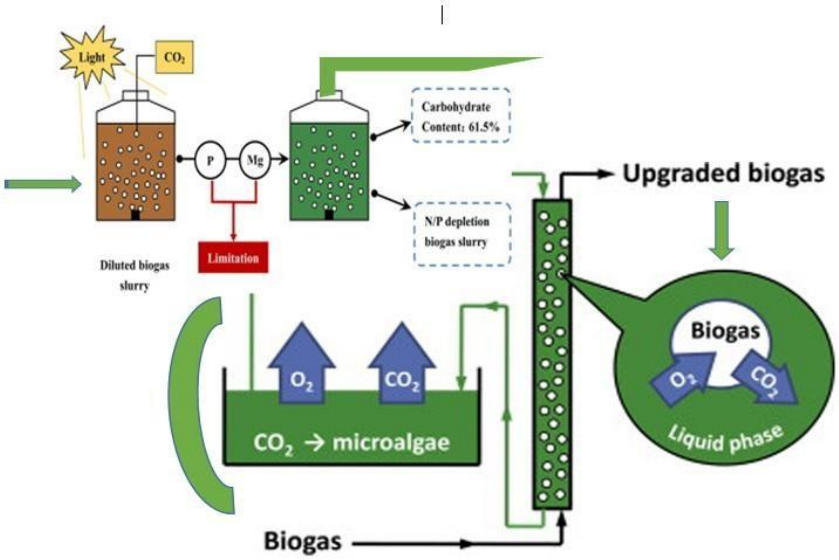
ABSTRACT

Wastewater is the excess water flow caused by water consumption in various human activities that can contain various physical, chemical and biological pollutants and endanger human health by polluting the environment. On the other hand, 99.9% of wastewater is water and only 0.1% of wastewater is external materials including soluble, suspended (sediment able/non-sediment able), organic and inorganic materials. However, the presence of such a seemingly small amount can cause irreparable damage to the environment. Nitrogen and phosphorus compounds in the effluent of wastewater treatment plants cause dangerous problems. Various methods and processes have been used to achieve the reduction of wastewater nitrogen to the standard level at different scales, one of which is the A_2/O method in the activated sludge process. It can be shown that 87% of the oxygen required for the nitrification process can be recovered, meaning that this method can be very effective in reducing energy consumption for the use of air blowers.

GRAPHICAL ABSTRACT



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Introduction

Wastewater is the excess water flow caused by water consumption in various human activities that can contain various physical, chemical and biological pollutants and endanger human health by polluting the environment [1]. On the other hand, 99.9% of wastewater is water and only 0.1% of wastewater is external materials include soluble, suspended (sediment able/non-sediment able), organic and inorganic materials. But the presence of such a seemingly small amount can cause irreparable damage to the environment. This issue has been addressed in each country in the constitution of each country [2-4]. If it is possible to separate waste and harmful substances from the wastewater at the treatment plant and bring the amount of pollutants in it to the specified level based on the defined standards, it can be hoped that the discharge of wastewater, i.e. treated wastewater, into the receiving water will not be a problem for the ecosystem and the environment [5-7]. What is clear is that in the design of municipal wastewater treatment plants, attention should be paid to the extent of these compounds from wastewater, and systems designed for municipal wastewater treatment should be able to remove nitrogen and phosphorus compounds to the standard level [8]. Further, in order to achieve the recommended standards, it is sometimes necessary to remove both nitrogen and phosphorus. Also, biological processes to remove these two contaminants are relatively easily combined with standard activated sludge systems. These factors have led to the use of various systems to do this [9-11]. In all these systems, the basic components are the same, including anaerobic, anoxic and aerobic sections, whose difference is in the number of components, their order and the places of flow return [12-13]. One of these processes is A_2/O (Anaerobic-Anoxic-Oxic) which is used when it is only necessary to remove ammonia (nitrate formation) and remove nitrogen [14]. In this process, an anoxic zone is placed between anaerobic and aerobic, which removes ammonia and reduces the nitrate load in the return sludge to the anaerobic zone [15]. Due to the presence of this area, some nitrogen is removed under the influence of nitrification process, which improves the efficiency of this system to remove phosphorus. Because the presence of nitrate in the return sludge entering the anaerobic zone reduces the efficiency of phosphorus removal. In any case, by returning the nitrified mixed solution from the aerobic portion, oxygen in the chemical compounds enters it as nitrate with nitrite. The expected density of phosphorus in the effluent is less than 1 mg/lit without leaching; by filtering the effluent, the phosphorus density may be less than 2.5 mg/lit [16].

Experimental

Pollution of water resources and comprehensive pollution reduction plans

The rate of growth and development is affected, proportional to the degree of sustainability in environmental, economic and social systems. Economic and social development will not be sustainable without considering the limitations of environmental systems [17]. Also, the level of contamination in water bodies is exceeding their self-purification capacity. Examining the existing problems, especially in the field of environment has necessitated the need to review the existing structures and laws in these countries in the field of decision-making and to present plans with sufficient comprehensiveness to solve the existing problems such as comprehensive pollution reduction plans [18]. Comprehensive plans for water resources development and pollution reduction are also of special importance as one of the tools for creating sustainability in the development and exploitation of water resources. Identifying the quantitative and qualitative problems in the studied water resources system is the first step in formulating the structure of comprehensive pollution reduction plans. For this purpose, it is necessary to identify the components of the system, the interactions and the relationship between them. Improving the use of social,

economic and environmental data and information at all levels of management and decision-making, which have a direct impact on the effectiveness of pollution control and reduction plans, are also of particular importance. Design and exploitation of sampling and monitoring systems are also of special importance in improving the quantitative and qualitative data required for system modeling and evaluation of pollution reduction projects in achieving the objectives of the comprehensive plan. These systems provide the necessary information of index variables that show changes in the quantitative and qualitative status of the system [19].

In municipal wastewater, mainly of household origin, nitrogen is present in organic and ammonium forms. These compounds are mainly wastes from protein metabolism in the human body. In fresh wastewater, about 60% of nitrogen is organic and 40% is ammonium. Bacterial decomposition of hydrolyzed protein compounds of urea converts organic nitrogen to ammonium nitrogen [20]. Fresh wastewater typically contains a small amount of nitrogen (less than one percent) in the form of oxidized nitrate or nitrate. Phosphorus is found in wastewater in the form of orthophosphate (PO_4^{-3}), polyphosphate (P_2O_7) and organic compounds of phosphorus. The last two compounds make up 70% of the input phosphorus. Microbes consume phosphorus during energy synthesis and transfer. As a result, 10 to 30% of the input phosphorus is released during secondary biological treatment [21]. But the key to success in the biological isolation of phosphorus is to expose microorganisms to alternating anaerobic and aerobic conditions. When microorganisms are exposed to alternating conditions, they become so stressed that their phosphorus uptake will be higher than normal. Not only is phosphorus used for cell maintenance, synthesis and energy transfer, but also it is stored for the subsequent use of microorganisms. Organic nitrogen in raw wastewater may be converted to ammonia. This conversion takes place through the bacterial decomposition of protein materials and the hydrolysis of urea. In any biological treatment system, there is always some bacterial growth, because 12-13% of the dry cell mass is nitrogen, some ammonia nitrogen is absorbed by new cells. Spontaneous oxidation and cell lysis will also occur, depending on the filtration process and loading conditions. Therefore, a part of the ammonia used for cell synthesis returns to the wastewater through spontaneous lysis and oxidation [22].

Residual adsorbed nitrogen can be removed from the system as pure growth or excreted biological sludge. Under the right conditions, ammonia nitrogen can be converted to nitrate during a two-step process. This process, which is performed in the presence of oxygen by two groups of microorganisms (nitrates), is called nitrification (nitro-so Monas and nitro bacter). Eventually, nitrate may be converted to nitrogen gas through a process called denitrification. This conversion takes place in the absence of oxygen by nitrate-removing microorganisms. An organic carbon source is needed to carry out the nitrate removal process. The nitrogen gas produced enters the atmosphere. About 1 mg N/lit of organic nitrogen will remain as a nonbiodegradable solution in the effluent. In order to maintain the nitration process to the maximum level, the density of dissolved oxygen must be increased by decreasing the SRT (time of solids to perform the nitration process). However, it should be noted that with a decrease in SRT, the rate of oxygen consumption increases due to carbon oxidation, thus the penetration of oxygen is reduced. Conversely, at high SRTs, the low rate of oxygen consumption allows oxygen to penetrate even at low oxygen density, and thus nitrate formation occurs at high rates. In the case of phosphorus, the aeration effect is such that with increasing aeration rate, the phosphorus removal efficiency decreases. The relationship between total phosphorus density and aeration rate can be described by a linear equation. If we consider the category of sludge, at aeration rates the density of

total phosphorus in the sludge age of 15 days is less than the sludge age of 30 days. Due to the mechanism of biological phosphorus removal, it is expected that the efficiency of phosphorus removal to be higher at low aeration rates. The description of the nitrate removal equilibrium reaction depends on the amount of the present carbon material. The reaction of methanol, which is widely used as a source of carbon output, is as follows:

(1) $6\ NO_3^- + 5\ CH_3OH \xrightarrow{\text{denitrifying bacteria}} 3\ N_2 + 5\ CO_2 + 7\ H_2O + 6\ O$

The experimental reaction of cell synthesis is:

(2) $NO_3^- + 0.08CH_3OH + .0.245\ CO_3 \rightarrow 0.06\ C_5H_2NO_2 + 0.42\ N_2 + 1.68\ H_2O + HC$

The amount of nitrification also depends on the temperature and density of dissolved oxygen [23].

Challenges and opportunities in using optimization models in water resources management

According to the mentioned cases, it is clear that one of the basic grounds of water resources management in the current situation is the optimal use of available resources. In order to consider the various dimensions and complexities of water resources systems, today managers and planners have resorted to the use of optimization models as an efficient tool to achieve optimal decisions.

A variety of evolutionary, deterministic and nondeterministic, static and dynamic, linear and nonlinear optimization models are used in various aspects of water resources management. The development of human knowledge and the creation of new tools and their combination with existing optimization models have provided new opportunities to make better decisions in the development and planning of water resources [24].

Creating tools and the need for access to modern technology such as the World Wide Web and GIS Information, value of new data and information due to behavioral changes in watersheds and the importance of rapid use of this information for analysis, design and information in emergencies and public education for water consumption and saving have created new coordinates in water resources management [25].

Today, with the rapid development of information technology, a new way has been provided for the development of new tools for the analysis, planning and management of water resources systems. With access to the internet, an infinite amount of information and sciences is provided to the user, which can be used to reach the most effective decisions. Useful tools that have been significantly expanded are remote sensing and GIS. Using remote sensing, quantitative and qualitative variables can be identified and effective parameters about them can be measured and the relationships between them can be interpreted.

For example, using information from sensors on airplanes and satellites, valuable information such as soil moisture, snow cover, and flood spread can be obtained, which are of great importance in the management of water resources. GIS is a special type of information system which its main purpose is to make decision for land, resources and geography management [26].

Better understanding of the reasons for differences and the spread of public knowledge and its share in the optimization process

There are always problems in the decisionmaking process of water resources management due to the existence of different sectors of consumers and producers of wastewater and effluents, because different sectors have different goals, views and priorities, and the final decision should be in such a way that all these differences have been considered [27].

Among the most important differences in water resources cited by the researchers, we can

mention the quantity and quality of water allocated to different sections, the quantity and quality of wastewater and effluents, which will suffer damage if the system is not managed properly. Limited resources and increasing water needs, due to population growth and development of cities and new community management policies, cause problems and differences in water allocation. Through thorough knowledge about the reasons for the differences and modeling those different methods and including them in the optimization models along with resolving the dispute, the researchers can assure that the results of the developed model will be feasible and practical. Cooperation and participation of different departments in the preparation and formulation of water resources management policies can facilitate the management and implementation of policies in management and reduce disputes at the same time. Increasing the level of knowledge and public awareness in relation to subjects, points and issues raised in optimization has led to improving the process of this integration.

By changing patterns, there is a need for new tools and methodologies related to water supply and consumption management that both reflect the complexities of the system and are able to develop and measure the stability of the system now and in the future. These new tools rely on a systematic perspective.

A systematic perspective is a kind of systemic attitude and thinking that allows for better identification of issues, problems and disadvantages and facilitates understanding and analysis. In addition, the systematic perspective is detailed and seeks to examine the goals of groups and systems with the help of modeling and effective use of information and management tools. The speed of the nitrate removal process under aerobic conditions will depend on the anaerobic part of the biological clot and the presence of a carbon source.

Table 1. Nitrate content in the use of different carbon sources

Temperature °C	Nitrate removal rate of gNO_3-N $X_{gNvss\text{-}day}$	Carbon source
28	0.35- 0.42	Methanol
18	0.2- 0.7	Methanol
14-24	0.05- 0.14	Domestic waste water
1-3	0.074-0.52	Domestic waste water
8-13	0.042-0.095	Self-hybrid metabolism

General solutions to improve the process

To improve the activated sludge process, the following measures can be used:

- Allocation of part of the aeration pond to anoxic and anaerobic areas and its conversion to A2/O process;
- Using the creek regime instead of complete mixing, which in addition to producing less sludge, removes organic matter much faster. Aslo, unlike full mixing, which has a linear removal diagram, in this case the diagram increases logarithmically;
- Changes in the structure of the ponds by simply changing the shape of the cross section ⊔ to U or even V, a significant part of the dead space in the depth of the ponds can be eliminated;
- Providing sufficient carbon resources to perform processes efficiently and determine the optimal amount of F/M

Conclusion

Today, water, this vital resource, is considered more than ever as one of the three factors of formation and survival of the environment, i.e. soil, air and water. Undoubtedly, the preservation and protection of water resources and the optimal, economic and fair use of water are a global issue today; therefore, in the 21_{st} century, water is mentioned as a pervasive human challenge. The focus of the international community is on

governments and nations' looking at water as the key to development. Although water resources are renewable, their volume is constant and, in contrast, human demand for it is increasing so in the last 100 years, global demand for water has more than six fold, while the population has tripled. Thus, water per capita is decreasing for the people of the world. On the other hand, unfortunately, pollutants such as industrial effluents, agricultural sewage and urban and rural sewage pollute water resources and make them out of consumption standards. Therefore, the optimal use of water resources is very important. In addition to the need for optimal operation and in order to develop methods to increase the confidence of users and managers due to the complexities of water resources systems, today the use of models has highly developed and different types of models are used in micro and macro decisions of water resources systems. Besides using the existing set of models, there are many opportunities and challenges for managers and planners who, by recognizing them and using them properly, can take very effective steps in using up-to-date knowledge and applying it in the service of water supply which is a basic human need.

Planning, designing and managing water resources systems to achieve the goals of sustainable development in an area requires public participation. All those involved in the development and management of water resources must always evaluate the effects of the system on economic, social as well as environmental changes. In order to achieve sustainable development, the issue of sustainability in all dimensions of planning, design, structure and operation must be considered. Economic and environmental analysis must not only consider the stage of development, operation and maintenance of the system, but also the possibility of its destruction and the need for its replacement. Water resources management activities can be divided into three categories: Formulating water resources management policies, managing measures to achieve policy goals and evaluating their effects. Macro water resources management policies, in fact, determine the relationship between development and exploitation of these resources with national development goals. The first step in formulating macro policies for water resources management is to propose different options according to the limitations and comprehensive goals of water resources development and management. The principles embedded in the current structure of water resources management organizations consider water resources as the main element of land management and sustainable development of land area, which should be managed by a single organization in the natural boundaries of the basin, so that creating opportunities for public participation and cooperation would probably be the most effective factor in the evolution of water resources management system. Sometimes it is necessary to remove both nitrogen and phosphorus to meet the recommended standards. In addition, biological processes to remove these two contaminants are relatively easily combined with standard activated sludge systems. Due to the presence of this area, some nitrogen is removed under the influence of nitrate removal process, which improves the efficiency of this system to remove phosphorus, because the presence of nitrate in the return sludge entering the anaerobic zone reduces the phosphorus removal efficiency. The amount of mixed liquid back from the aerobic to anoxic region is 100 to 300% of the inlet flow to the treatment plant. As a result of the performance of this process, about 40 to 70% of nitrogen is removed. However, the ability of this process to remove phosphorus is somewhat less than the A/O (only phosphorus removal) process. The suggestion here is to place the grilles between the aerobic and anoxic zones. By installing lattice plates, made of concrete or asbestos, the mixture created in the aerobic zone by nozzles or surface aerators in the wastewater is not transferred to the anoxic zone. On the other hand, the dimensions of the holes are selected in such a way

that the pressure drop does not appear and the flow passes different stages of the treatment. The most obvious advantage of this idea is to prevent dead areas in the aeration pond, which causes effective aeration to the sewage, and also reduces the volume of ponds and the accuracy of control parameters such as stay time and the amount of air required due to the exact volume of ponds. Aeration and anoxic increase significantly. The most obvious advantage of this idea is the prevention of dead areas in the aeration pond, which makes aeration occur more efficiently in the sewage and does not allow it transfer to the anoxic zone. Also, the volume of ponds is reduced and the accuracy of control parameters such as stay time and the amount of air required due to the accuracy of the volume of aerated and anoxic ponds are significantly increased.

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Declaration of Competing Interest

The authors declared that they have no conflicts of interest to this work.

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Disclosure Statement

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