MME SEE

CONGRESS 2023

5th Metallurgical & Materials Engineering Congress of South-East Europe

Trebinje, Bosnia and Herzegovina

7-10th June 2023

CONGRESS PROCEEDINGS

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SEQUENCING BATCH REACTOR SYSTEMS FOR THE TREATMENT OF WASTEWATER

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Releasing untreated or inadequately treated effluents into recipients (rivers, lakes, and oceans) can endanger aquatic ecosystems and drinking water sources. In order to eliminate harmful pollutants, wastewater must be treated, especially industrial wastewater enriched with nutrients. Phosphorus contamination can occur through a variety of different routes, such as wastewater treatment plant discharge (municipal and industrial), agricultural fertilizer losses from erosion, drainage, etc. The establishment of suitable wastewater treatment techniques is essential. The subject of this paper is the biological removal of nutrients (phosphorus) from wastewater, using unconventional methods of wastewater treatment - sequencing batch reactors (SBR) systems. Their modifications and the advantages such processes offer, compared to the standard activated sludge (AS) treatment that is the most often used, will be presented. Enhanced biological phosphorus removal methods that employ various microorganisms have been observed from the perspective of the method's effectiveness. Of all applied treatments for phosphorus removal, the most effective and the most often used was the accumulation of polyphosphates in the biomass itself. The purpose of this paper is to offer a brief review and theoretical essentials of environmental engineering techniques that can be applied in real industrial wastewater treatment plants.

Keywords: environmental pollution, biological treatment, nutrient removal, sequencing batch reactors.

Introduction

Biological treatment of wastewater can be done in several ways [1]. In fact, without the removal of nutrients before releasing them into a recipient, negative consequences like eutrophication can appear which would upset the environmental balance. One of the most frequently applied and best-tested systems is the Sequencing Batch Reactor (SBR).

The SBR process was primarily used to treat sewage wastewater from smaller communities and some industrial wastewater. With the advancement of technology, the SBR process has found its application in the biological treatment of wastewater. Compared to the conventional activated sludge process, a well-optimized SBR process requires significantly shorter aeration time, which can reduce operating costs by up to 60%, while maintaining the desired effluent quality [2]. What makes this process attractive is the wide range of application possibilities. It can be used for the treatment of sanitary and industrial wastewater. It is characterized by a high degree of aeration control, so aerobic, anaerobic or anoxic conditions can be provided depending on the needs of the treatment. SBR process can be applied independently for wastewater treatment, in combination with other processes, or it can be used for pre-treatment and post-treatment [3].

The wastewater treatment in SBR consists of 5 stages:

$$\text{filling phase} \rightarrow \text{reaction phase} \rightarrow \text{sedimentation phase} \rightarrow$$
$$\rightarrow \text{decanting phase} \rightarrow \text{idle phase} \rightarrow \text{filling phase} \rightarrow \cdots$$

In a continuous Activated Sludge Process (ASP) these operations occur simultaneously due to a continuous fluid flow, while in SBR they are performed one by one. More than one reactor can be utilized in line, but each of them must perform all the basic operations of this process. Given that it is a batch process, the duration of each stage can be adjusted to meet different treatment requirements such as low chemical oxygen demand (COD) in the effluent accompanied by effective biological removal of nutrients.

In the first phase (*filling phase*), the reactor receives raw wastewater, which comes into contact with the active biomass left at the end of the previous cycle. Depending on the characteristics of the wastewater and the required level of removal efficiency, there are three variations of this phase: static, with aeration and combined. This phase is characterized by a high ratio of nutrients to biomass, stimulating the growth of bacteria that form flocs, and inhibiting the growth of undesirable filamentous bacteria, which provides good conditions for the further pathway of this process. Additionally, appropriate conditions are created for organisms that accumulate phosphates. The *reaction phase* is the phase in which organic matter is broken down, and it is often designed to remove unwanted nutrients. Depending on the needs, aerobic, anaerobic, anoxic conditions, or a combination of some of the mentioned conditions can be established in this phase. During the *sedimentation phase*, the entire reactor acts as a precipitator, microorganisms are separated from the treated effluent under the influence of gravity. In the fourth stage, fixed or floating decanters are used to separate the supernatant formed after settling in the previous stage. The *idle phase* is the time between decanting and refilling the reactor with a new volume of wastewater.

Materials and methods

Cyclic Activated Sludge System – CASS

This is a system that incorporates a single reactor with a variable operating volume and variable operating modes (Figure 1). Activated sludge is recirculated from the reactor and mixed with raw wastewater at the entrance to the reactor. The biological selector ensures the stable and uniform metabolic activity of sludge during recirculation and thus enables faster consumption of organic matter and sustainability of flocs. In such a reactor, it is possible to achieve better efficiency of phosphorus removal compared to the standard SBR system [4]. Such a system can be used for the treatment of both industrial and municipal wastewater.

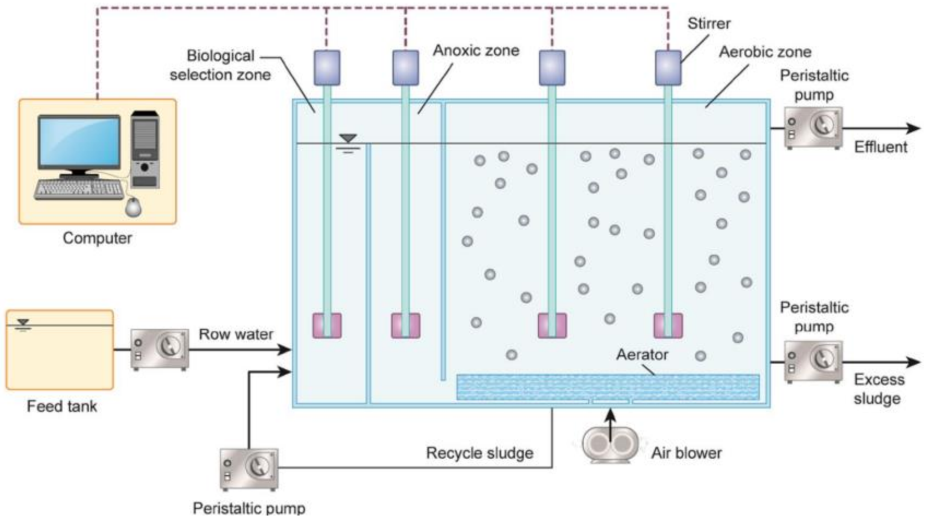

Figure 1 CASS schematic diagram [4]

UNITANK

UNITANK technology combines the advantages of SBR with a regular aeration tank and three oxidation compartments [5,6]. The most common UNITANK configuration consists of a single tank divided into three hydraulically connected compartments. Each compartment has an aeration system but is not provided with a recirculation system. The section in the middle serves only for aeration, while the outer sections, in addition to aeration, are also used for sludge sedimentation and are supplied with drainage channels.

One operational cycle consists of two main phases, which each have 3 basic steps. The advanced UNITANK configuration has additional anaerobic/anoxic compartments supplied with a recirculation system. The advantages of such a system are its simple structure, it takes up little space, it is reliable and relatively cheap to operate, but it is not suitable for larger wastewater treatment plants.

Intermediate Cycle Extended Aeration System - ICEAS

This system is an improved version of the conventional SBR system. It is designed to process a continuous flow of wastewater, by distributing the influent to several tanks, so that one tank does not become overcrowded. In addition to the main reaction zone, this system also includes a secondary reaction zone, which is located in front of the main one. The secondary reaction zone has a high ratio of nutrients to microorganisms and acts as a selector, which improves the subsequent sedimentation of sludge and inhibits the growth of fibrous bacteria in the main reaction zone. Three phases are carried out in the main reaction zone: the reaction phase, the sedimentation phase and decanting. The equal distribution of incoming wastewater in different tanks enables easier control of the process, as well as maintenance. Capital investments necessary for this process are significantly lower than for conventional SBR. This variation of the SBR can be used as a stand-alone wastewater treatment plant, or to upgrade an existing one.

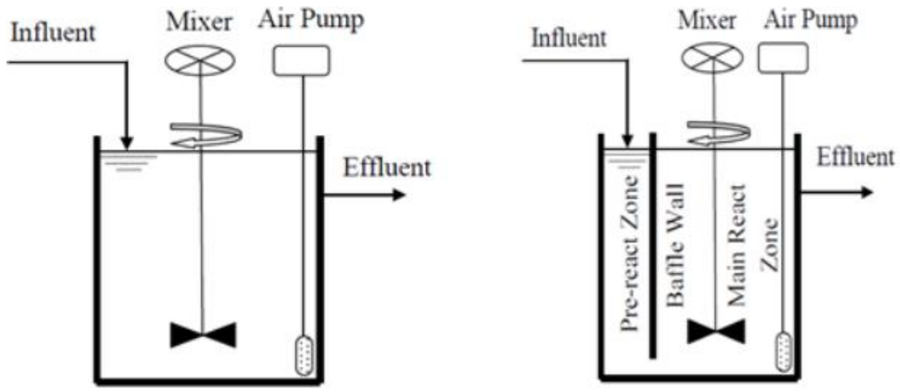

Figure 1 Reactor Schematic Diagram: a) SBR, b) ICEAS [7]

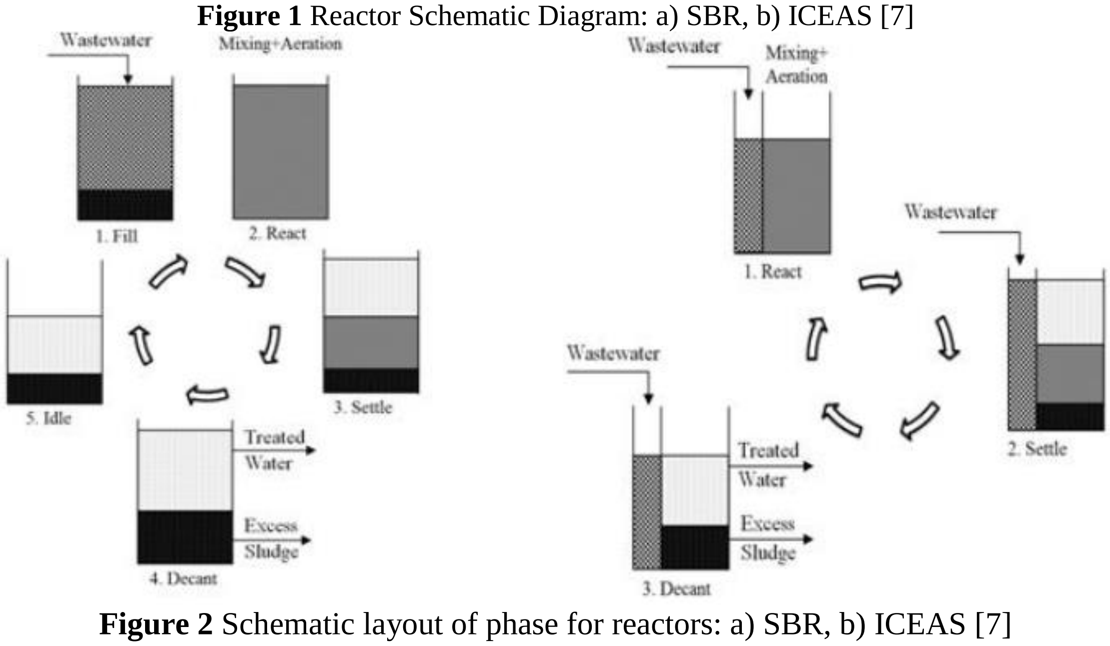

Figure 2 Schematic layout of phase for reactors: a) SBR, b) ICEAS [7]

Enhanced biological phosphorus removal - EBPR

Phosphorus removal during wastewater treatment is a necessary procedure and can be done in several ways [8]. A special group of organisms that accumulates polyphosphates (PAO) is used for the process. They incorporate phosphorus from the influent into the cell biomass. For this process, it is preferable to alternate anaerobic and aerobic conditions. Under anaerobic conditions, PAOs use volatile fatty acids as the primary source of carbon and store it in the form of polyhydroxyalkanoate (PHA). Energy for this process is obtained mainly by hydrolysis of stored intracellular phosphates, causing the excretion of orthophosphate into the water, or by hydrolysis of intracellular glycogen by glycolysis [9]. Under aerobic or anoxic conditions, PAOs can, using stored polyhydroxyalkanoates as an energy source, bind excess phosphorus from intracellular polyphosphate formations and thus ensure cell growth and replenishment of polyphosphate and glycogen stores. A phosphorus removal efficiency of up to 90% can be achieved in SBR. The presence of glycogen-accumulating organisms (GAO) can prevent or inhibit biological phosphorus removal because they compete for the source of volatile fatty acids with PAO. GAOs can use volatile fatty acids under anaerobic conditions and convert them into PHA. The difference is that the energy for this GAO process is obtained exclusively from the hydrolysis of glycogen. GAOs do not release orthophosphates and cannot bind and transform phosphorus, so they do not contribute to phosphorus removal. To prevent this, it is necessary to adjust the conditions in the reactor so that they favor the growth of PAO over GAO [1,9].

Analysis of samples from laboratory systems and wastewater treatment plants where biological phosphorus removal was performed revealed the presence of bacteria from the genus *Rhodocyclus* from the class *Betaproteobacteria* [10]. Combining FISH (fluorescence in situ hybridization) and MAR (microautoradiography) methods during the investigation of PAO related to *Rhodocyclus* (RPAO) from wastewater treatment plants showed that RPAO can bind short-chain fatty acids including acetate, pyruvate and propionate, but not formic acid, glucose and ethanol. Glycolysis was essential for anaerobic substrate consumption. In addition to RPAO, gram-positive bacteria belonging to the section *Actinobacteria* capable of accumulating inorganic phosphorus were also found. Some of these bacteries are *Microlunatus phosphovorus* and *Tetrasphaera elongate* [10]. The aerobic accumulation of inorganic phosphorus by this group of bacteria depended on their ability to bind glucose (*M. phosphovrorus*) or amino acids (*T. elongata*) under anaerobic conditions (instead of short-chain fatty acids). The behavior of these bacteria was unexpected. None of them formed PHA, so they were not considered significant for the process of biological phosphorus removal. Intracellular stores of polyphosphates have been found in some other *Actinobacteria*. These bacteria are *Tetrasphaera australiensis*, *Tetrasphaera japonica*, *T. elongata* (Lp2 variant, with short rods), *Tessaracoccus bendigoensis*, filamentous *Candidatus Nostocoida limicola* and *Candidatus Microthrix parvicella* [10].

These bacteria have been found to have the ability to bind inorganic phosphorus and to accumulate polyphosphates using oxygen or nitrate as an electron acceptor. The physiology of these bacteria is significantly different from RPAO. By analyzing a sample from a wastewater treatment plant (Skagen, Denmark), it was determined that the most numerous PAOs were from the genus *Tetrasphaera*, family *Intrasporangiaceae* belonging to the section Actinobacteria (APAO). The genus consists of 3 main species, *T. australiensis*, *T. japonica* and *T. elongate* [10]. APAOs use amino acids as a substrate. It is not completely clear which amino acids they use, because there were 15 different amino acids in the substrate, but it is known that they do not use aspartic acid, glutamic acid, glycine and leucine. APAO did not generate PHA during anaerobic substrate consumption. Glycolysis in APAOs did not have a particular role in the anaerobic consumption of substrates, while RPAOs have to break down internal glycogen by glycolysis, to provide energy for the formation of PHA.

The mechanism by which APAOs store the energy produced by the anaerobic degradation of the substrate required for the binding of inorganic phosphorus is not known [9,10].

Conclusion

Innovative approaches to removing phosphorus from small-scale wastewater treatment facilities are required due to the increasingly strict criteria for phosphorus reduction. The metabolic mechanisms linked to rich phosphorus uptake by bacteria and algae, which offer an alternative practical, environmentally friendly, and affordable approach for phosphorus removal at smaller scales, have been the subject of promising research. Nevertheless, particularly in the case of biological treatment approaches, obtaining significant levels of phosphorus removal via such systems frequently comes at the sacrifice of system simplicity. This brief review manuscript aimed to represent mostly used SBR systems for the biological removal of phosphorus. Many different technologies can effectively remove phosphorus, but at the cost of increased energy use, heightened operating complexity, and/or unnecessary maintenance. Namely, three different reactor systems were shown: Cyclic Activated Sludge System – CASS, UNITANK, and Intermediate Cycle Extended Aeration System - ICEAS) with a description of the functioning of these systems. New options are needed that provide a better balance between simplicity, effectiveness, and sustainability at smaller scales. The ecological sensitivity of remote watercourses and the potential for increased regulatory pressure, demands investment in the development of a broader range of small-scale phosphorus removal technologies.

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