RESEARCH ON WASTEWATER TREATMENT USING ACTIVATED SLUDGE TECHNOLOGY IN THE ANAEROBIC-ANOXIC-AEROBIC CONFIGURATION

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Municipal wastewater management has become one of the most challenging environmental issues due to the increasing volume of urban wastewater and strict regulations imposed on the concentration of effluent pollutants. In the present case, the influencing disturbances of pollutant concentration and flow rate, temperature changes that influence/affect the complex biochemical processes that take place in bioreactors were simulated. This approach was considered in the present research, approaching the Alexandria municipal sewage treatment plant using activated sludge technology in the Anaerobic-Anoxa-Aerobic intensive configuration.

The improved model was developed in a biological installation based on activated sludge, coupled with a modified version of the simulation model in which anaerobic-anoxic-aerobic phases were alternated.

The simulation results ensure the simultaneous removal of organic substances, nitrogen and phosphorus, eliminate the addition of an additional carbon source for the denitrification process, reduce the sludge volume by about 15%, reduce energy consumption by about 30%.

Keywords: wastewater treatment, temperature malfunctions.

1. Introduction

Following the modernization of the sewage treatment plant in the Municipality of Alexandria, Teleorman County, the effluent met the requirements of the EU Directive on the treatment of urban wastewater 91/271/CEE [1], as well as the national legislation.

This includes maintaining biochemical oxygen demand (BOD) below 25 mg/l, chemical oxygen consumption (CCO) below 125 mg/l, suspended solids (MS) below 35 mg/l, total nitrogen (Nt) less than 10 mg/l and total phosphorus (Pt) less than 1 mg/l.

Achieving these targets has significantly improved the quality of the water in the Vedea river downstream of the station, especially since the wastewater from

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the treatment station represents almost 10% of the natural flow of the water course.

This has led to a cleaner environment by reducing nuisances such as odors, floating waste, unpleasant watercolor; at the same time increasing the ecological value of the river and reducing groundwater pollution.

All these aspects led to the increase in the level of water use for irrigation and fish farming, with beneficial socio-economic effects. Considering the aspects presented above, no additional mitigation measures are necessary, apart from the monitoring of effluent discharges to ensure that the installation complies with the limits imposed by the legislation in force.

It should be mentioned that in the process of expanding and rehabilitating the station, account was taken of the volumes of water/charges that needed to be purified, as well as the main environmental and social obligations that must be fulfilled in accordance with the Environmental Agreement and national regulations and the EU.

A level of flexibility has been maintained regarding the exact way of fulfilling the compliance requirements (for example: equivalent persons, size and dimensioning of pools, barbecues, etc.), but also of the wastewater treatment processes which include a combination between the mechanical stage (of example: sparse and dense gratings, sand filters, grease separators and basins for primary sedimentation) and the biological stage (for example: using an activated sludge process), respectively secondary sedimentation basins.

Together, all this technology removes between 70-90% of pollutants before discharge into the emissary [2]. The project to expand and rehabilitate the sewage treatment plant aimed from the very beginning to identify, manage and mitigate the potential environmental and social impact associated both in the construction phase and in its operation phase.

Considering that the treatment plant has been modernized, it still requires substantial amounts of energy for key operations, such as water and sludge pumping, aeration of activated sludge basins, respectively dewatering, all of which are a challenge for the Beneficiary to find new solutions. It should be emphasized that the noise level at the location is below the limit provided in STAS 10009/2017 [3], i.e. below 65 dB(A), for noise reduction, key equipment such as centrifuges or blower stations or mounted in isolated premises phonics.

The purpose of the present research in the present case is to analyze the functioning of the treatment plant presented above, equipped with a mechano-biological treatment stage, where it was highlighted that the influent of the treatment plant falls within the regulated limits of most of the standardized quality indicators, less for elements with a eutrophic character (nitrogen and phosphorus forms).

The influencing disturbances of the pollutant concentration (nitrogen and phosphorus the main nutrients) are determined by the temperature changes that influence/affect the raw waste water collection processes and reveal the fact that in the collectors with deficiencies (concrete carbonates, collectors with small slopes) and small flows that do not ensure the speed of self-cleaning, erroneous conception of the collector, etc.) the transformation of organic nitrogen into ammoniacal nitrogen is achieved [4].

Nitrogen

At the entrance to wastewater treatment plants, nitrogen is present in organically bound form (organic N) and as ammonium nitrogen (NH_4-N). During biological wastewater treatment, organic N is converted to NH_4-N by NH_4-N activated sludge bacteria and NH_4-N from the inlet is converted to nitrite which in turn is converted to nitrate (nitrification).

The nitrogen compounds that are not biodegraded in the activated sludge are transformed in anoxic conditions (absence of dissolved O_2) into elemental nitrogen (denitrification). It is released into the atmosphere as N_2.

• Nitrogen compounds are determined as NH_4-N, NO_2-N, NO_3-N and TN (total nitrogen, which is important for equilibrium and efflux checks).

Phosphorus

The P loading in the influent of wastewater treatment plants consists of phosphorus orthophosphate (PO_4-P), polyphosphates and organic phosphorus compounds. Together, they add up to "total phosphorus" (P_{tot}).

In the case of the present research, it is necessary to respect the limits of the Normatives in force regarding the concentration of nitrogen and phosphorus elements, advanced purification processes (in the Anaerobic-Anoxa-Aerobic intensive configuration) must be applied to urban wastewater.

2. Materials and methods

Based on the research data, it was highlighted that the removal of nitrogen and phosphorus compounds from urban wastewater can be achieved by applying advanced purification technologies in biological purification basins provided with 3 phases: anaerobic, anoxic and intensive aerobic.

(a). nitrogen removal through the suspended biomass process - by alternating anaerobic, anoxic, aerobic conditions;

(b). removal of phosphorus by accumulation in active biomass - by alternating conditions anaerobic with aerobic ones [5];

(c). removal of phosphorus by adsorption (retention on synthetic zeolites) and by precipitation.

(a). Nitrogen removal by the process with biomass in suspension - by alternating conditions anaerobic, anoxic, aerobic

The experimental installation on which tests were carried out is a biological installation with activated sludge, with a multiphase bioreactor, in which an alternation of anaerobic - anoxic - aerobic phases was achieved.

Fig. 1 shows the technological flow diagram applied within the advanced purification installation in a multiphase system that provides for a biological purification system with activated sludge, without an additional source of carbon, in which an alternation of anaerobic, anoxic and aerobic conditions is achieved.

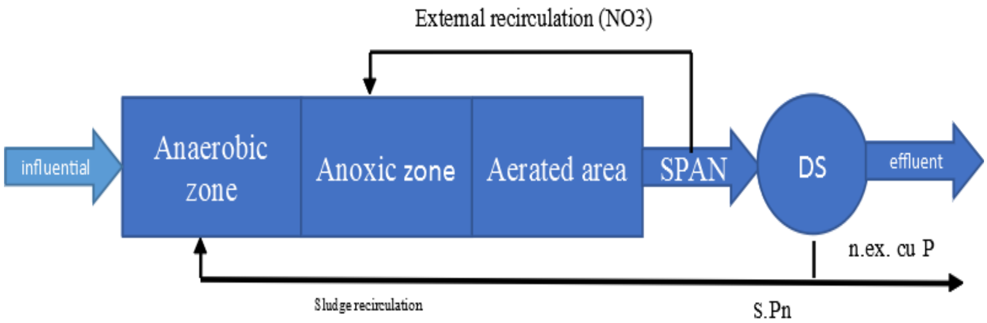

Fig. 1 Technological flow diagram Biological treatment basins provided with 3 phases: anaerobic, anoxic and intensive aerobic [6]

The compact installation of this type presents a number of advantages, as specified in the literature of specialty [7, 8, 9] namely:

• ensures the simultaneous removal of organic substances, nitrogen and phosphorus;

• the addition of an additional source of carbon to carry out the process is eliminated denitrification;

• the volume of sludge is reduced by about 15%;

• energy consumption is reduced by about 30%.

The average nitrogen removal efficiency achieved in the activated sludge plant during the experimental period was approx. 50% for ammoniacal nitrogen and 63% for total nitrogen. In order to keep the nitrification-denitrification processes under control, it must be specified that the installations are automated.

It should be noted that the classic purification installations can be adapted and completed in order to ensure the optimal parameters necessary for the nitrification - denitrification and phosphorus removal processes.

Method of determination

The method applied below in Fig. 2 is well known as the UCT System (designed at the Technical University of Cape Town) [10] - to overcome the interference of nitrogen and phosphorus removal processes. This is possible if the following are provided:

• recirculation of activated sludge rich in nitrates from the aerobic zone to the anoxic one (recirculation coefficient r1 = 100 - 200%);

• additional recirculation of the liquid from the anoxic zone to the anaerobic one (recirculation coefficient r2 = 100 - 200%);

• the UCT technology is capable of denitrifying the nitrates contained in the sludge activated by external recirculation before they are recirculated in the anaerobic zone.

It should be mentioned that the external recirculation coefficient can vary between 50 - 100%.

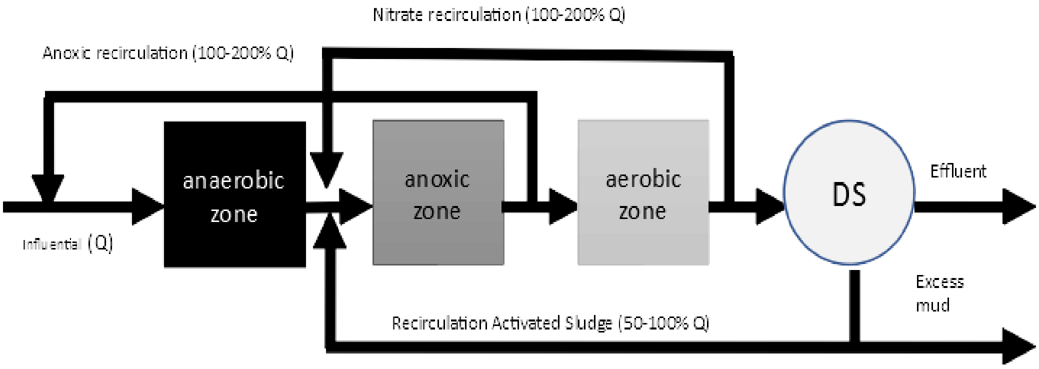

Fig. 2 Scheme of the UTC purification process [10]

In table 1, the total nitrogen values, input and output parameters recorded at the treatment plant are analyzed, during the monitored period of 12 months, it is observed that the compact installation with activated sludge maintains the total nitrogen (N_t) within the allowed limits of less than 10 mg/l.

Table 1

Variations in total Nitrogen values recorded between January and December 2022 [11]

Month	Average monthly value of Total Nitrogen entrance mg/l	Average monthly value of Total Nitrogen at the exit mg/l
January	26.6	9.3
February	21.4	9.8
Marty	29.2	9.41
April	27	9.90
May	24.4	9.2
June	22.4	8.86
July	27	9.90
August	23.8	9.75
September	24.2	7.68
October	27.2	9.1
November	22.90	9.6
December	21.90	9.8

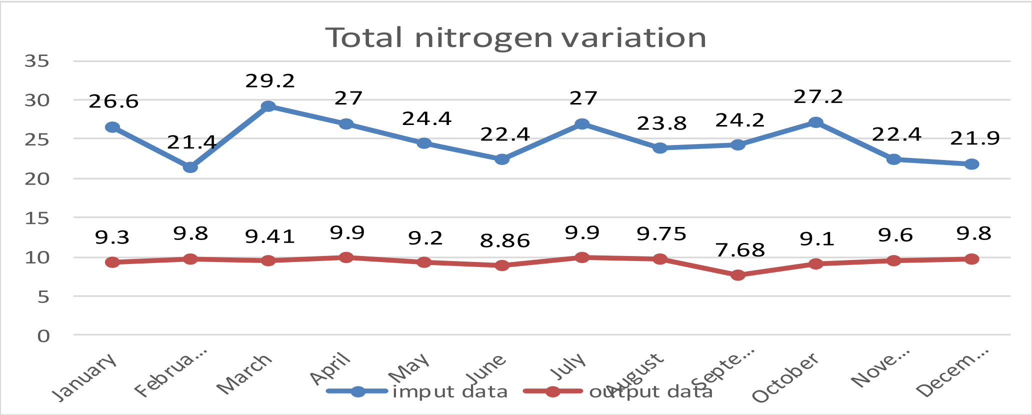

Fig. 3 the variations of the Total Nitrogen values at the entrance to the Treatment Plant were monitored during 12 calendar months (water samples) and it was found that the toxicity of the water samples decreased, they remained below the allowed level of N_t less than 10mg/l at the emissary exit.

(b). Phosphorus removal by accumulation in active biomass - by alternating anaerobic and aerobic conditions

Phosphorus can be removed during biological treatment processes by accumulation in active biomass. This is achieved either by the precipitation of inorganic phosphorus (extracellular precipitation) in special environmental conditions, or by the accumulation of phosphorus by the microorganisms themselves, as an intracellular reserve. In order to obtain the biological elimination of phosphates, it is necessary to alternate between anaerobic and aerobic conditions. In the acidogenic anaerobic phase, Aeromonas (facultatively anaerobic) bacteria use the organic carbon in the wastewater to produce acetate.

The presence of nitrates in the environment prevents the activity of these microorganisms, therefore denitrification is necessary. The acetate produced is reused by the bacteria of the genus Acinetobacter/Moraxelle, being stored in the form of PHB (polyhydroxybutyrate). Technologically, phosphorus removal processes can be carried out in sequential anaerobic - anoxic - aerobic reactors, where nitrogen can also be removed through the nitrification - denitrification process.

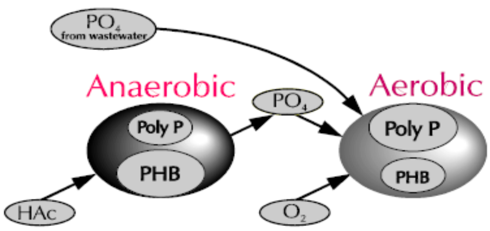

Fig. 4 Diagram of the biological removal mechanism of phosphorus from wastewater [12]

(c). Phosphorus removal by adsorption (retention on synthetic zeolites) and by precipitation

From the obtained results, the possibility of using type A and type X cationic forms for the retention of phosphate ions was highlighted. Under the studied conditions, the retention capacity of phosphate ions, for both zeolitic structural types, varied in the order: Na-Ze < Ni-Ze < Ca-Ze < Cu-Ze. It was highlighted that X-type zeolites show an increased efficiency compared to A-type ones and that the adsorption equilibrium is established after about 2 hours.

The retention mechanism of phosphate ions from dilute solutions is based on their retention in the adsorption cavities, while the retention from concentrated solutions is based on a complex mechanism.

The most economical and simplest method for removing phosphates from wastewater is based on precipitation of phosphorus with reagents containing ionic forms of aluminum, iron and calcium.

The basic principles of the technical procedures lead to the elimination of phosphorus by precipitation with the help of Fe^{3+} (in the form of $FeCl_3$ solution), Al $^{3+}$ (in the form of aluminum sulfate solution), Ca^{2+} (in the form of $Ca(OH)_2$). Solutions formed at a pH of 6-7 for aluminum ($Al(OH)_3$ x H_2O) and 6-9 for iron ($Fe(OH)_3$ x H_2O) are hardly soluble, flocculent and settle well.

The precipitation processes proceed quite slowly, the reaction times required for the three reagents of precipitation requires to be fixed between 30 and 60 minutes. The amounts of precipitation reagents theoretically required are based on the stoichiometric conversion of PO_4^{-3}.

The installation for the preparation - dosing of reagents for phosphorus precipitation

The preparation plant - dosing reagents for phosphorus precipitation, under normal operating conditions - in combination with the biological reduction of phosphorus in the anaerobic compartments integrated in the biological reactor - will ensure the elimination of P_{tot} until a concentration in the effluent of less than 1 mg/l is obtained.

The installation is able to remove the phosphorus of the entire influent up to a concentration of phosphorus in the effluent lower than 1 mg/l and in the situation where the phosphorus is not biologically removed.

The capacity of the preparation plant - dosing reagents for phosphorus precipitation covers all scenarios from the maximum dosing capacity (without biological removal of phosphorus in anaerobic basins) to the minimum dosing (in situations of minimum input flow).

Method of determination

The phosphorus removal efficiency was determined by taking into account the phosphorus concentration in the wastewater before and after precipitation. For this, samples were collected from the influent and effluent of the installation, over an interval of 3-4 hours. Momentary samples were collected, with a frequency of every 30 minutes. Average samples were also composed from momentary samples. The concentration of total phosphorus (from average samples) and ortho-phosphates (from momentary samples) was determined from the collected samples.

Also, in addition to the actual phosphorus precipitation process, the process of sedimentation. For this purpose, the content of suspended matter in the effluent of the installation was determined.

Comparative analysis regarding the phosphorus removal efficiency in the two scenarios flow capacity Q_{ZI}, med. 15638 m^3/day and flow Q_{ZI}, max. 19613 m^3/day, the results being the following:

• For P removal by precipitation and flocculation where the following calculation formula was used for the chemical determination of P that must be chemically removed:

Equations

$$P_{chemical} = P_{in} - P_{out} - P_{BM} - P_{reduced\ bio} \quad (1)$$

Table 2

Concentration of phosphorus loads that must be removed chemically

No.	P concentration	stock mg/l
1.	P entry	7.20
2.	P output = 0.70*P effluent	1.40
3.	P incorporated in biomass = 0.01 C	2.03
4.	Biologically reduced P	1.02
5.	P required to be chemically precipitated	2.75

Table 3

Quantities of phosphorus loads that must be chemically removed

No.	P concentration	amounts Kg/day
1.	P entry	112.59
2.	P output = 0.70*P effluent	21.89
3.	P incorporated in biomass = 0.01 C	31.75
4.	Biologically reduced P	15.95
5.	P required to be chemically precipitated	43.00

The calculation result for the chemical determination of P using a 100% $FeCl_3$ precipitation agent is 2.70 Kg Fe for the precipitation of 1 Kg Phosphorus to which we add the molecular weight for Fe of 55.85 g/mol, respectively for Cl of 35.50 g/mol. Amount of precip solution/day will be 337.53Kg/day.

The research carried out has shown that the removal of phosphorus from urban wastewater can be effectively carried out in biological treatment basins provided with 3 phases: anaerobic, anoxic and intensive aerobic.

In table 4, the total Phosphorus values, input and output parameters recorded at the treatment plant are analyzed, during the monitored period of 12 months, the biological efficiency provided with the 3 phases: anaerobic, anoxic and intensive aerobic which maintains the total Phosphorus (P_t) within the permitted limits of less than 1 mg/l.

Table 4

Variations in Total Phosphorus values recorded between January and December 2022[11]

Month	Average monthly value of Total Phosphorus entrance mg/l	Average monthly value of Total Phosphorus at the exit mg/l
January	3.08	0.55
February	2.84	0.93
Marty	2.64	0.78
April	4.45	0.94
May	3.93	0.62
June	3.18	0.79
July	4.16	0.82
August	3.68	0.98
September	4.24	0.99
October	3.59	0.91
November	2.25	0.87
December	2.81	0.9

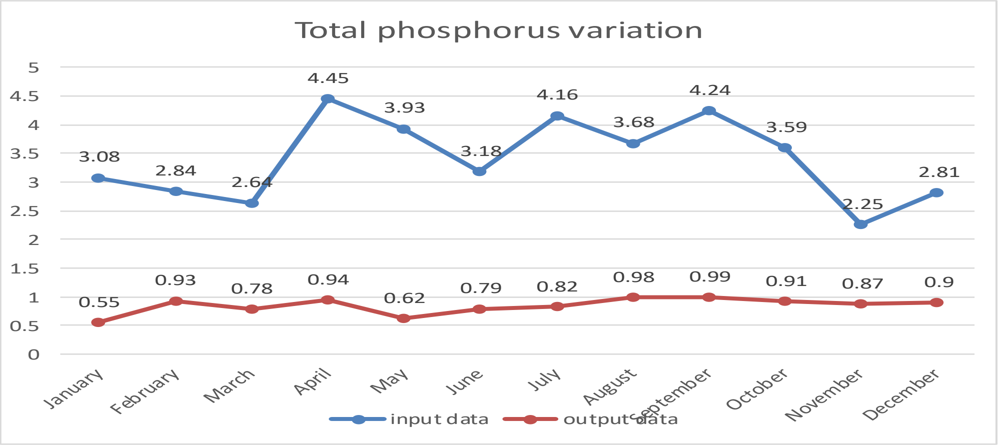

Fig. 5 the variations of the total Phosphate values at the entrance to the treatment plant were monitored during 12 calendar months (water samples) and it was found that the toxicity of the water samples decreased, they remained below the permitted level of lower P_t. more than 1mg/l when leaving the emissary.

Aerobic composting of sewage sludge

Considering that the aforementioned treatment plant has been modernized, it still requires substantial amounts of energy for key operations, such as dehydration, this being a challenge for the Beneficiary to find new solutions such as aerobic composting.

Dewatered sewage sludge, stabilized anaerobically, is flexible and lends itself to treatment by composting due to the low C/N ratio.

Materials such as natural zeolites (clinoptilolite) [13], are used as fillers due to their ability to increase the porosity of the substrate and improve the composting process and the biodegradation of organic matter.

Composting can concentrate (Cr, Mn, Ni, Pb, Zn) or dilute (Cu, Fe) heavy metals present in sewage sludge. Natural zeolite has the ability to exchange sodium and potassium.

Increasing the content in zeolite, the concentration of all heavy metals in the sludge decreases and the concentration in sodium and potassium increases.

Conversion to fertilizer can take place in closed reactors or in the open air "window" (an established term in the international professional literature, of English origin) meaning "heap".

If the composting process is conducted correctly, there are no differences in terms of ripening time. The closed system has the advantage of offering a great possibility of control compared to the open system.

In order to highlight the advantages resulting from the composting of the sludge obtained from the city sewage treatment plants, their composting with household street waste (leaves, grass, branches resulting from cleaning the parks) was studied.

For this, sludge resulting from the treatment plant (mixture of primary and biological sludge) was mixed with biodegradable household waste and street waste, the proportion being 65% sludge from the treatment plant and 35% household waste in a total of $1m^3$ of mixture. This mixture was placed on a covered concrete platform, creating a pile that was aerobically composted in an open system.

During the composting period, the humidity was maintained between 58-69% (water was added at intervals). In the first month of the experiment, the compost was mixed (aerated) once every two days, and in the second month once a week. The initial temperature from which composting started was 37°C.

The quality of the compost was analyzed resulting in the following values:

- pH = 6.90;
- organic carbon = 28.2%;
- NT = 1.80%;
- C/N = 19;
- PT = 0.42%.

With the decrease in the composting temperature and entering the constant temperature level, it was considered that a large part of the organic substance has fermented, and the quality of the compost was determined by obtaining the following quality indicators:

- pH = 7.62;
- organic carbon = 18.90%;
- NT = 1.51%;
- C/N = 10.5;
- PT = 0.35%;

The application of sewage sludge to agricultural soils is regulated in Directive 86/278/1986 [1]. It is recommended that no more than 0.15 kg/ha/year of cadmium, 6 kg/ha/year of copper, 3 kg/ha/year of nickel, 6 kg/ha/year lead, 18kg/ha/year zinc and 0.1 kg/ha/year mercury. When establishing these limit values, the fact that urban sludge is not the only source of heavy metal pollution of agricultural soil was taken into account.

For the evolution over time of the characteristics of the compost, its quality indicators were initially analyzed during the composting period, following their evolution over time.

The mixture of sludge from the sewage treatment plant with vegetable residues showed the following characteristics after homogenization of its composition:

- pH = 7.35;
- organic carbon = 30.12%;
- NT = 1.5%;
- C/N = 21.23;

3. Conclusions

Based on the experimental data, it was highlighted that the removal of nitrogen and phosphorus compounds from urban wastewater can be achieved by applying advanced purification technologies in biological purification basins provided with 3 phases: anaerobic, anoxic and intensive aerobic. Classic treatment plants can be adapted and completed in order to ensure the optimal parameters necessary for the nitrification-denitrification processes and increase the efficiency of removing pollutants from wastewater (mainly nitrogen, phosphorus and metals).

The content of fertilizing elements (nitrogen and phosphorus) can be an advantage if mechano-biologically purified waters are used for irrigation of agricultural crops. Aerobic composting of sludge, as an alternative biotechnology, allows the exploitation of the organic matter and nutrient content of sewage sludge from city plants as fertilizer or soil amendment and further reduces operating costs [14].

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