# Nutrient Removal from Industrial Wastewater Systems Using Controlled Activated Sludge Treatment

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Abstract: Biological treatment with activated sludge as an alternative treatment was studied, and nitrogen and phosphorus were monitored. This scheme involves modifying the treatment tank by dividing it into anoxic and aerobic sections. According to this scheme, the process simulation was performed using Hydromantis' GPS-X 7.0 computer software. Wastewater discharges are usually generated by various industrial activities such as the milk (dairy) processing industry, petroleum processing refineries and slaughterhouses, which were studied in detail. The economic evaluation (cost estimation) of removing nutrients has been done using the CapdetWorks 4.0 computer simulation software. A cost sensitivity analysis has also been performed for the variable influent flows, altering the alpha factor for oxygen transfer during the aeration process and serving as a typical variable. The simulation procedure and economic evaluation have been carried out for a complete wastewater treatment plant, including both treatment lines (the water line and the sludge line simultaneously), and the derived results have been represented through illustrated graphs, tables, and meaningful diagrams.

Keywords: industrial wastewater, biological treatment, nutrient removal, activated sludge, simulation, economic evaluation

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## 1. Introduction

Wastewater results from both human activities and various industrial processes, as well. It is well-known that these discharges contain pollutants of multiple natures that significantly impact the environment, human beings, and other living organisms. This is why they must be treated before their release into receiving waters [1-3].

*Wastewater Treatment Plants* are the structures set up for this purpose. In these plants, a series of chemical, physical and biological processes are carried out, which aim at removing pollutants and bringing the values of the characteristic parameters of waters back within the allowed values so that they do not threaten the environment and the living organisms. The purpose of this paper is to study the biological treatment of wastewater using the activated sludge process. If the conventional natural treatment scheme is modified, this is a very efficient treatment process for removing organic matter and nutrients, such as nitrogen and phosphorus, from wastewater [4-6].

Using simulation methods, results have been obtained for the treatment process in two different configurations: a configuration that includes only the biological treatment process for nutrient removal and a design that provides for all the treatment processes that take place in a typical wastewater treatment plant, where activated sludge is used as a biological treatment. The economic evaluation for these two configurations has also been carried out, and results have been obtained from a cost-sensitivity analysis of parameters such as the influent flow or the value of the alpha factor for oxygen transfer during the aeration process [7-10].

### 1.1 Wastewater characteristics

Total water discharges include urban discharges, industrial discharges and infiltrations. The characteristics of water discharges are divided into three categories:

- Physical characteristics (Total Solids, temperature, colour, turbidity, smell and odour).

- Chemical characteristics (pH, fat, oil and grease FOG, nutrients, chemical and biochemical oxygen demand COD and BOD, dissolved oxygen DO, chloride content, metals, etc.).

- Biological characteristics (bacteria, viruses and protozoa)

The following material describes the biological method for nutrient removal.

### 1.2 Biological nutrient removal

Two common nutrients in water discharges are nitrogen (N) and phosphorus (P). Those two compounds have to be removed from the wastewater since they are responsible for the eutrophication of receiving waters [11-12].

### 1.3 Nitrogen biological removal

Different forms of nitrogen can be found in wastewater, and natural degradation can be performed under other conditions and by different organisms. Organic nitrogen consists of a complex mixture of compounds, including amino acids, sugars and proteins. This form of nitrogen is usually neglected in wastewater treatment because it undergoes a biological process, ammonification, in the sewer system and is converted to ammonia before arriving at Wastewater Treatment Plants [1].

There are two different processes for biological nitrogen removal: nitrification and denitrification [2]. Oxidation in nitrite is performed by specific bacteria called Nitrosomonas, while further oxidation in nitrate is performed by bacteria called Nitrobacteria. Both these steps are carried out under aerobic conditions. During the denitrification process, nitrates are converted to nitrogen gas. This process occurs under anoxic conditions and requires a carbon source such as methanol [3].

### 1.4 Phosphorus biological removal

Total phosphorus in wastewater consists of different forms of phosphorus, such as organic phosphorus in orthophosphates and phosphorus in polyphosphates, which undergo hydrolysis and turn into orthophosphate. Phosphorus biological removal processes are related to the alternating exposure of microorganisms to aerobic and anaerobic conditions. Phosphorus is used for the growth of the microbial colony, its maintenance and energy transport, and is also stored by the microorganisms for further use. Thus, phosphorus is also removed with the removal of microorganisms [4-6]. During anaerobic conditions, these microorganisms assimilate the fermentation products of biodegradable organic matter and produce PolyHydroxyButyrate (PHB) using the accumulated polyphosphates as an energy source, a process that is accompanied by the release of orthophosphates. Thus, in the cellular biomass during anaerobic conditions, the concentration of PHB increases and that of polyphosphates decreases [7, 8]. During the aerobic phase, the PHB is an energy source for new cell growth. The energy released by the oxidation of PHB is used to absorb phosphorus in the cells of microorganisms, thus reducing its concentration in water discharges. Finally, the phosphorus-rich sludge is separated from the treated water [9-12].

### 1.5 Wastewater Treatment Plants

Wastewater generated by industrial processes and urban discharges, or municipal wastewater, must be treated before its final discharge to receiving waters; for this purpose, the Wastewater Treatment Plants have been set up. These plants consist of two treatment lines:

- The first treatment line, also known as the water line, includes the treatment of water discharges for pollutant removal [13].

- The second treatment line, also known as the sludge line, includes the treatment of the sludge generated from the first line processes and its final disposal.

The first treatment line includes the following processes: *Pretreatment, Primary treatment, Secondary treatment, Tertiary treatment, and Disinfection.*

The second treatment line consists of the following processes: *Thickening, Digestion, Dewatering, and Final disposal.*

### 1.6 Biological Treatment using Activated Sludge Process

The activated sludge biological treatment mainly consists of four components: an aeration tank, a secondary sedimentation tank, a pump for sludge recycling and distributors for oxygen supply, as shown in Fig. 1.

Microorganisms come into contact with the organic matter dissolved in polluted water and use the energy of chemical bonds between C, H and other elements as food and for the growth of the microbial colony.

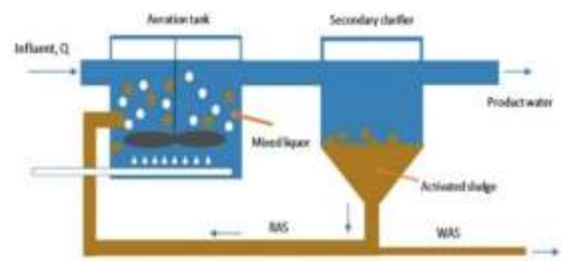


Fig. 1. Conventional activated sludge process treatment (source: https://h2omspl.com/activated-sludge-process-asp/)

Thus, the organic material is broken down into CO2, H2O, other compounds and more microorganisms. After the biological reactions are carried out for a certain amount of time in the aeration tank, the mixed liquid, ML (the mass of microorganisms mixed with the polluted water in the presence of oxygen), is sent to the secondary clarifier where the solids, MLSS, are separated from the water (settling). One part of the sludge is recycled into the aeration tank, and the remaining is removed as waste and sent to the second treatment line. Nutrients such as N and P can also be removed through biological treatment by modifying the aeration tank and dividing it into three sections: anaerobic, anoxic, and aerobic [14-16].

## 2. Materials and Methods

For nutrient removal, a process simulation for a modified activated sludge process treatment scheme was applied using a GPS-X simulator by Hydromantis. Samples from different industries in Albania have been tested according to the following order: A specific library of simulators called "Petrochemical Wastewater Library (mantisiwlib)" has been used to simulate the petroleum processing industry's discharge treatment process [17-18]. The "Comprehensive – Carbon, Nitrogen, Phosphorus, pH (mantis2lib)" library has been used for the remaining types of water discharges, then studies water discharges generated by slaughterhouses before and after treatment, followed by water discharges outflow from the milk processing industry, and finally water samples coming out from a petroleum processing industry—the economic evaluation of those two schemes using CapdetWorks software, also by Hydromantis.

## 3. Results and Discussion

Our study was started by constructing a process diagram (Fig.2) for a modified activated sludge process treatment scheme for nutrient removal. Then, the protocol of process simulation is applied using the GPS-X simulator issued by Hydromantis Co. The calculations for the petroleum processing industry discharge treatment process have obtained the results.

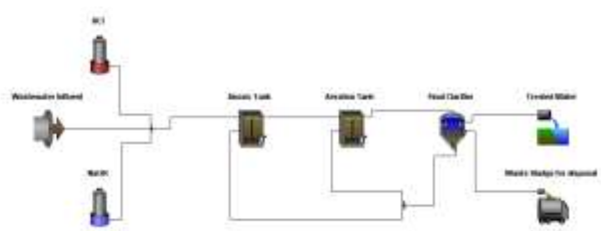

**Fig. 2:** Simulation diagram of the treatment process

Properties of the wastewater from the petroleum industry are shown in Fig. 3:

### 3.1. Case of discharges generated by slaughterhouses

Properties of the wastewater outflow from slaughterhouses before and after treatment are shown in Fig.4: Numerical results have been disciplined in Tables 1 and 2, respectively, for slaughterhouse wastewater properties before and after treatment.

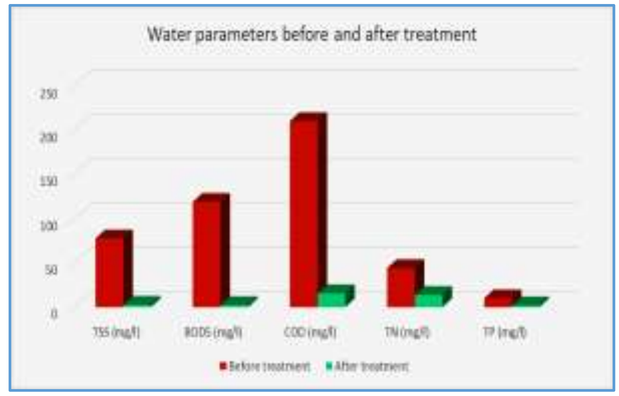


**Fig. 3:** Characteristics of water discharges generated by the petroleum processing industry before and after treatment

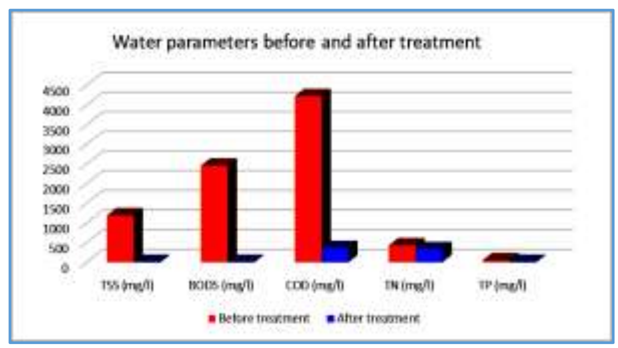


**Fig. 4:** Characteristics of water discharges generated by slaughterhouses before and after treatment

**Table 1.** Wastewater parameters before treatment

| Water parameter | Slaughter houses | Milk processing industry | Petroleum processing industry |
|---|---|---|---|
| TSS (mg/l) | 1189 | 730 | 77.57 |
| $BOD_5$ (mg/l) | 2454 | 773.6 | 118.8 |
| COD (mg/l) | 4221 | 1500 | 210.0 |
| TN (mg/l) | 427 | 40 | 44.08 |
| TP (mg/l) | 50 | 10 | 10.0 |

**Table 2**. Wastewater parameters after treatment

| Water parameter | Slaughter houses | Milk processing industry | Petroleum processing industry |
|---|---|---|---|
| TSS (mg/l) | 10.43 | 5.50 | 2.73 |
| $BOD_5$ (mg/l) | 11.56 | 11.20 | 2.39 |
| COD (mg/l) | 362.1 | 93.79 | 15.72 |
| TN (mg/l) | 329.3 | 3.69 | 13.84 |
| TP (mg/l) | 11.38 | 6.02 | 2.01 |

**3.3** The case of properties parameters of wastewater discharged by a milk processing industry

The protocols for this case have been applied as for the previous case studies, and the results have been presented in Fig.5.

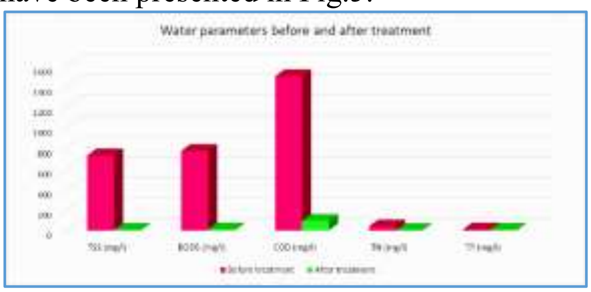


**Fig. 5:** Characteristics of water discharges generated by the milk processing industry before and after treatment

**3.4 A sensitivity analysis has been performed**, and the following results presented in Fig.6 have been obtained:

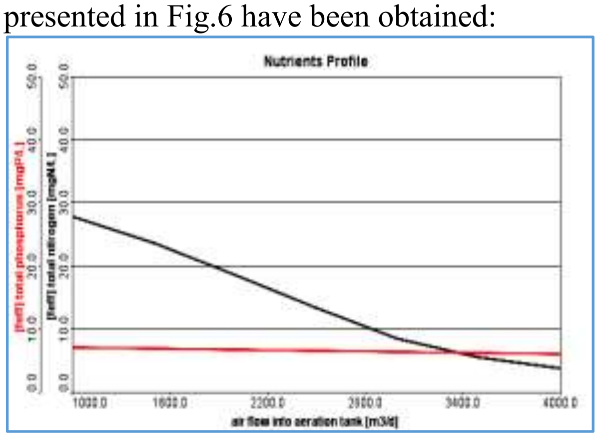


**Figure 6:** Nutrients, in mg/L profile variation from the airflow (in m3/d) into the air tank.

Considering the graphs and the table, the cost values are higher for the water discharges generated by slaughterhouse treatment. This is

### 3.4 Economic evaluation

Economic evaluation [9] was performed for the previewed treatment plant using CapdetWorks software by Hydromantis. A process flow diagram is shown in Fig.7

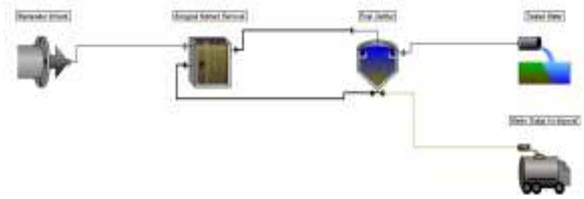

**Fig. 7:** Process Flow Diagram

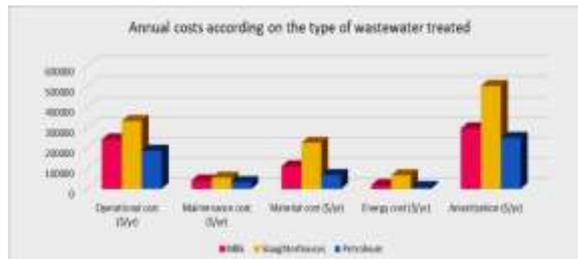


**Fig. 8:** Dependence of the Present worth value and project cost from the type of treatment plant for Milk, Slaughterhouse, and Petroleum wastewater, respectively

A cost estimation procedure has been carried out for the previewed wastewater treatment plant design, and the f results are graphically presented in Fig.8 and Fig.9:


**Fig. 9:** Dependence of the Annual cost from the type of wastewater treatment plant for Milk, Slaughterhouse, and Petroleum wastewater, respectively

## 4. Discussions:

also related to the relatively higher values of the characteristic parameters of this discharge compared to the other types of discharges that have been studied.

Cost sensitivity analysis showed that the average influent flow and the alpha factor for oxygen transfer during the aeration process were variables.

On the other hand, water discharges from the milk processing industry showed variations in Fig. 10. The rest of the water discharges studied follow the same trend.

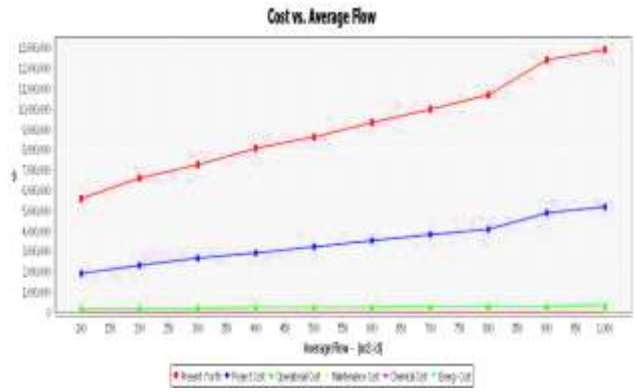


**Fig. 10:** Variation of the project cost vs. average flow (m3/d).

## 5. SIMULATION FOR A COMPLETE WASTEWATER TREATMENT PLANT

A complete plant simulation was then performed using a GPS-X computer simulator, and the following results have been obtained.

The whole plant flow diagram was firstly constructed for the complete treatment processes (shown in Fig.11) for the influent wastewater characteristics, which, as can be seen, are of an approximate value to typical ones found in real applications.

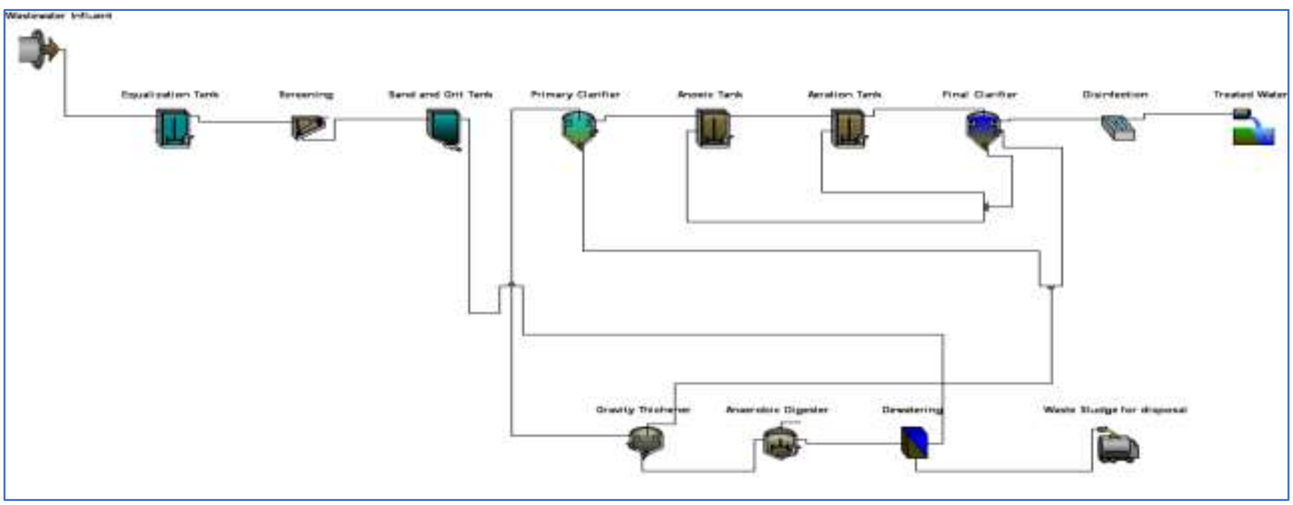


**Fig. 11:** Simulation diagram of the treatment process

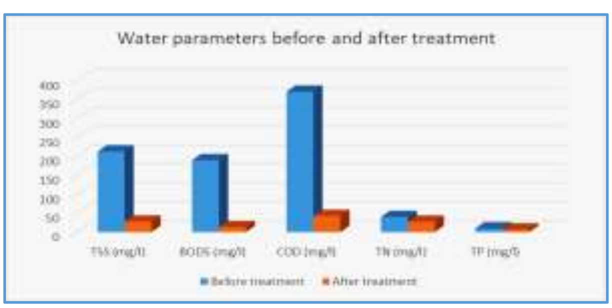


**Fig. 12.** Characteristics of water discharges before and after treatment

**Total Wastewater discharges' parameters before and after treatment:**

**A dissolved oxygen (DO) profile.**

This was monitored, calculated through a simulation process, and presented graphically (Fig.13).

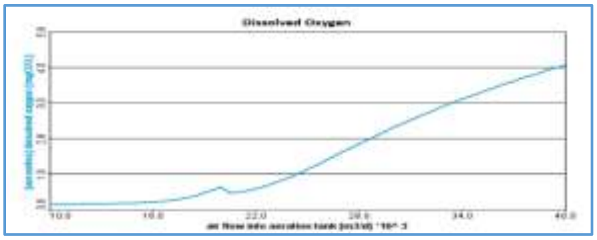

**Fig. 13:** Dissolved Oxygen profile

**Economic evaluation for the entire treatment plant**

Later, an economic assessment for the partial and total project was carried out (Fig 14, 15) using Capdet Works software, and the following results have been obtained:

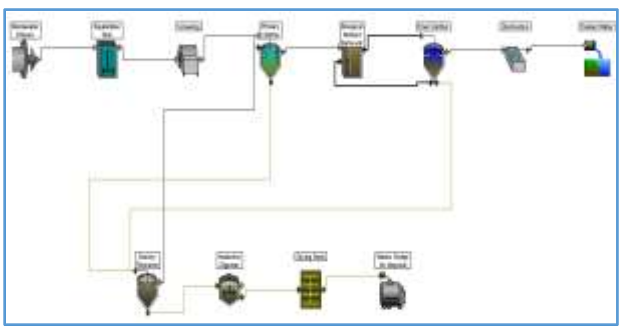

**Fig.14:** Partly Process Flow Diagram

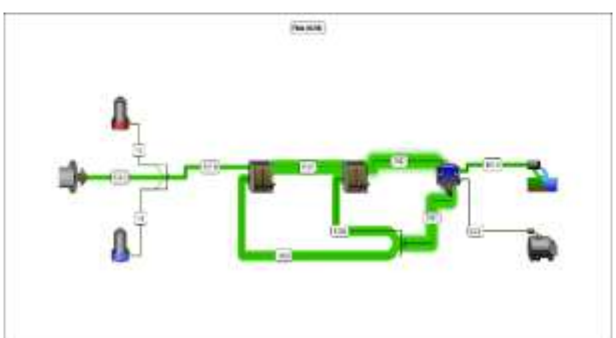

**Fig. 15**. Sankey Diagram regarding the plant capacity.

A sensitivity analysis has been performed, and the relevant results have been obtained:

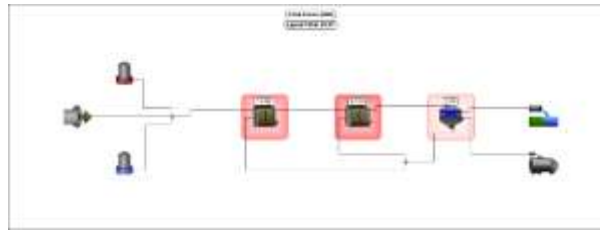

**Fig. 16**: Illustrative Diagram of the total energetic expenditures

**Last consideration for the entire project**

The objective of this paper was to study the biological treatment of wastewater using the activated sludge process (Fig.17). Focusing on nutrient removal, a modified treatment scheme was reviewed, which consisted of two divided treatment zones with different aeration conditions, an anoxic zone and an aerobic one (Fig 18).

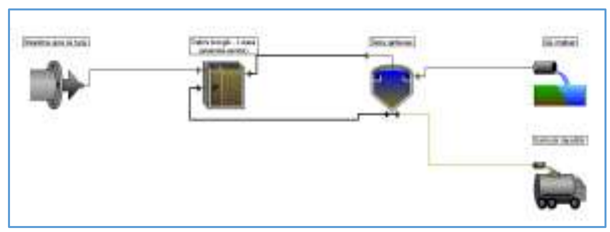

Fig. 17: Schematic presentation of the biological treatment of wastewater using the activated sludge process.

## 6. Experimentation in the Pilot Plant

To study the biological treatment process of water discharges with activated sludge, experimentation can be carried out in the activated sludge treatment pilot plant "PPFAC" monitored and computer-controlled by SCADA software from EDIBON Ltd (Spain). The main parts of the pilot plant and the working principle are described below.

### 6.1. Description of the pilot plant and the treatment process

The activated sludge treatment process consists of three main components:

– the biological treatment tank, where the polluted water is brought into contact with microorganisms,
– clarifying container for separating sludge from treated water,
– Active sludge recycling system from the clarification vessel to the biological treatment tank.

The pilot plant for computer-controlled activated sludge treatment, or otherwise Computer Controlled Activated Sludge Process Unit, "PPFAC", is designed to treat water discharges using activated sludge. The main parts of the planned plant are also described here, as well as the treatment process.

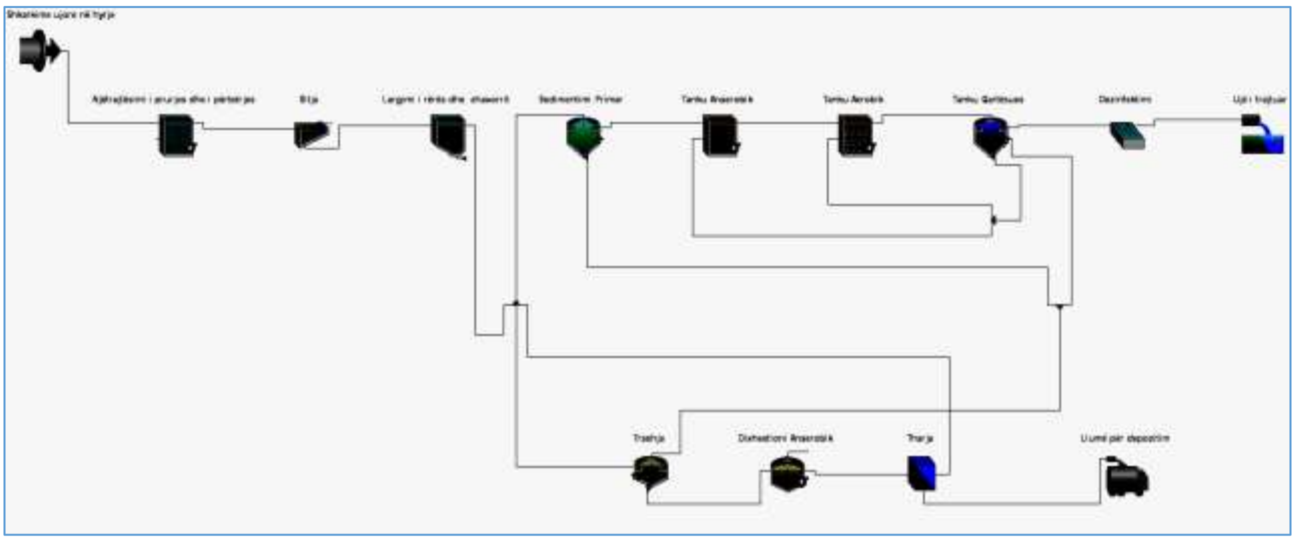

**Fig. 18:** Total Process Flow Diagram constructed with computer software CapdetWorks.

As a result of the simulation, the modified scheme was highly effective, as the values of the water parameters were significantly reduced. However, the nutrient values could have been further reduced, and a way to achieve that could be by adding an anaerobic tank in the treatment process. A complete wastewater treatment plant scheme with the activated sludge process was also studied (Fig.18). This scheme led to biogas production. Adding a two-stage anaerobic digestion process can enrich this product in methane. Illustrative drawings and accompanying figures show the pilot plant's main parts below.

## 7. Conclusions.

In this paper, the biological treatment of water discharges using activated sludge was studied based on a modified scheme, which, in addition to the removal of organic matter, also removes nutrients. Water discharges generated by the milk processing industry, petroleum processing industry and slaughterhouses were studied, and the reduction rate of water parameters after treatment are shown in the table below:

**Table 3.** Decreasing rate of water parameters after treatment

| | The reduction rate of water parameters after treatment (%) | | | | |
|---|---|---|---|---|---|
| Wastewater type | TSS | $BOD_5$ | COD | TN | TP |
| Slaughterhouses | 99.12 | 99.53 | 91.42 | 22.88 | 77.2 |
| Milk processing industry | 99.25 | 98.55 | 93.75 | 90.77 | 39.8 |
| Petroleum process industry | 96.48 | 97.99 | 92.51 | 68.60 | 79.9 |

Using simulation methods, a sensitivity analysis of the nutrient profile was carried out, with the airflow into the aeration tank as a variable, and it turned out that with the increase of the airflow, the nutrient concentrations decreased. The economic evaluation was carried out, and a cost sensitivity analysis was performed with the average influent flow and the alpha factor for oxygen transfer during the aeration process as variables. It resulted in an increase in the influent flow, which increased the cost values. In contrast, with the rise of the alpha factor's value, the cost values decrease because the aeration process is carried out more efficiently. Also, the simulation and economic evaluation of a complete wastewater treatment plant that includes both the water and the sludge lines was carried out. After treatment, the values of the characteristic parameters of water discharges were reduced by 87% for TSS, 93% for BOD5, 88% for COD and 31% for total nitrogen and total phosphorus. As a result of anaerobic digestion, biogas is produced, a mixture of mainly CH4 and CO2 gases, in fractions of 54% and 45%, respectively. This biogas can generate electricity for the treatment plant or distribution to the network. From cost sensitivity analysis, it turned out that with the increase in the influent flow, the cost values increase. In this work, the biological treatment of water discharges using activated sludge was studied, and the modified scheme was treated, which, in addition to the removal of organic matter, also removes nutrients such as nitrogen and phosphorus. The process simulation was carried out based on the pilot plant "PPFAC" configuration, which includes modifying the treatment tank to remove nutrients employing the GPS-X 7.0 simulator from Hydromantis. The simulation showed that the treatment process with activated sludge is efficient, leading to a decrease in the values of parameters such as BOD5, COD, TSS, nitrogen and total phosphorus and an increase in the concentration of dissolved oxygen in the water. The central part of the energy costs in the plant is related to the aerobic treatment process. The central part of operational costs in the plant is also related to the aerobic treatment process.

Then, the economic evaluation of this treatment process was carried out using CapdetWorks 4.0 software from Hydromantis. From the economic evaluation, some results were obtained with corresponding values for different cost items for the main processes of the plant, where an essential part of the values was related to the aerobic and anaerobic treatment process. An analysis of the sensitivity of different cost items was carried out about the flow at the plant entrance, from which it was found that with the increase in the flow of water discharges to be treated, the operational cost, maintenance and energy cost values increase. The analysis of the sensitivity of different cost items to the value of the alpha factor for the transfer of oxygen during the aeration process was also carried out. With the increase in the value of this factor, the operational cost, maintenance and energy cost values decrease after the ventilation process is carried out with higher efficiency. Also, the simulation and economic evaluation of a complete water discharge treatment plant was carried out, including both treatment lines, the treatment of the water mass and the treatment of the sludge. The simulation showed that the complete treatment process was very efficient as treated water was obtained with low values of the relevant parameters. This was also noticed by the results of a sensitivity analysis that was carried out for several parameters, from the airflow to the aeration tank. As expected, operational and energy costs for this plant were higher than in the treatment process based on the pilot plant configuration. However, their central part was related to the aerobic treatment process. However, a significant amount was related to the anaerobic treatment and anaerobic digestion. Due to anaerobic digestion, biogas is also obtained, a mixture of mainly CH4 and CO2 gases in 54% and 45% fractions. This biogas can generate electricity for the treatment plant or distribution to the network.

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The authors have no conflicts of interest to declare that are relevant to the content of this article.

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