Environment Protection Engineering

Vol. 30 2004 No. 4

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INTEGRATED REMOVAL OF CARBON, NITROGEN, AND PHOSPHORUS AT MODERNIZED WASTEWATER TREATMENT PLANT IN KOBYLEC

The paper discusses modernization of an industrial waste treatment plant for 7450 PE and gives an outline of the technological system and design principles of the plant prior to its modernization. A need to improve the effectiveness of carbon, nitrogen and phosphorus removal from wastewater is presented.

The modernization process consisted above all in eliminating the primary settling tank and sludge digestion chamber. Its aim was to implement aerobic sludge digestion and to create favourable conditions for the nitrification, the denitrification and the biological dephosphorization. A new technology system and the operating units of a plant are described. In conclusion, the authors present the evidence of higher effectiveness of carbon, nitrogen and phosphorus removal from sewage after modernization.

1. INTRODUCTION

An effective removal of carbon, nitrogen and phosphorus from wastewater is very difficult in small treatment plants. This is especially true in the case of phosphorus removal. In order to remove all phosphorus from wastewater, chemical precipitation is indispensable, which increases the operating costs of plant. Dealing with the sewage mixture that consists of industrial waste from such sources as dairy, commercial slaughter house and meat-processing plant necessitates a detailed analysis of their operation and more advanced technological knowledge.

The modernization described was undertaken after a break-down of a dairy waste treatment plant in Kobylec. Because of this break-down the dairy sewage was not pretreated which resulted in doubling the pollutant loads. The modernization was forced by the fact that the water intake was at the distance of 10 km from the outlet of sewage whose dilution was sixty-fold.

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2. CHARACTERISTICS OF SEWAGE TREATMENT PLANT BEFORE ITS MODERNIZATION

2.1. BASIC DESIGN PRINCIPLES

The flow rates of wastewater were as follows:
Mean daily $Q_{md} = 315\ \mathrm{m^3/d}$.
Mean hourly $Q_{mh} = 21\ \mathrm{m^3/h}$.
Max hourly $Q_{\max h} = 37.3\ \mathrm{m^3/h}$.

Table 1

Concentrations and pollutant loads in crude wastewater

	Concentration (g/m^3)		Load (kg/d)	
	Design data	Inlet*	Design data	Inlet
BOD$_5$	746	1420	235	447
Suspended matter	604	620	190	195
Nitrogen	87	100	28	38
Phosphorus	22	27	6.93	8.5

* Averaged samples from sampling in daily hours during the period of April 2003.

The sewage concentrations accepted in the project were lower than actual ones (table 1). The population equivalent designed (PE) was 3615, while the actual one reached 7450 because of an increased load supply to the treatment plant from the neighbouring industrial plants.

2.2. TECHNOLOGICAL UNIT SYSTEM OF THE TREATMENT PLANT BEFORE MODERNIZATION

Slot sand trap. The slot sand trap was made of PVC pipes, each having 40 mm in diameter. The pipes had slots being cut along 1/3 of their circumference, with 6 slots being cut in every pipe at equal intervals of 0.20 m. The slope was 1%. A floodable pump extracted the sand deposited in the chamber of the sand trap and directed it to the sludge drying bed. The quantity of sand $Q_s = 0.096\ \mathrm{m^3/d}$.

Grid basket. The volume of the grid basket was $V = 0.18\ \mathrm{m^3}$. The quantity of screenings was $Q_{sc} = 60$ kg/d. The grid basket was equipped with a mechanical winch to pull the basket out. The screenings were collected in a container.

Sewage pumping station. The sewage pumping station was equipped with a storage tank of the following dimensions: 3.2×2.9 m and a functional depth $h_{fd} = 1.6$ m, two pumps, each of a capacity of 6 dm^3/s.

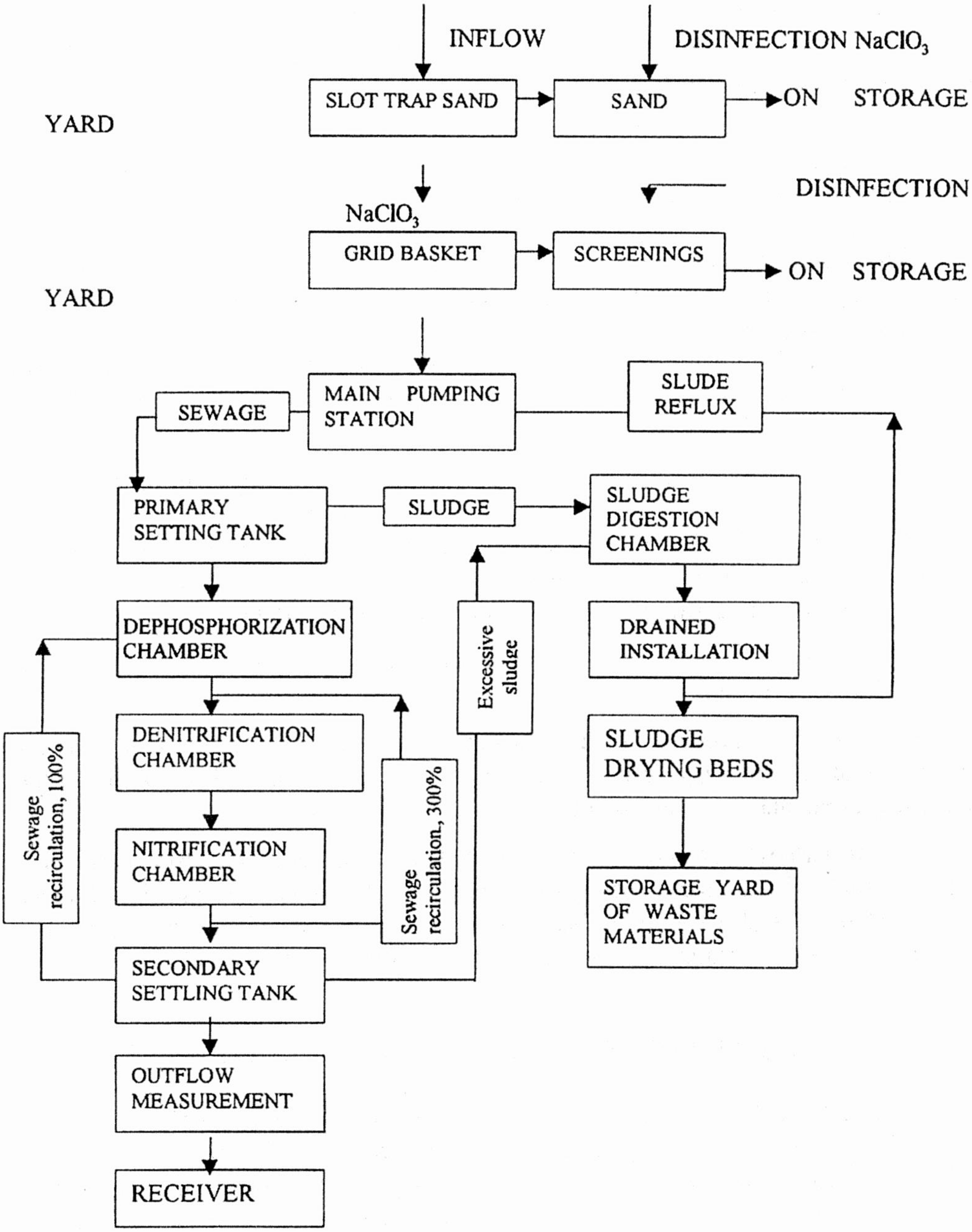

Fig. 1. Block diagram of sewage treatment plant before modernization

Primary settling tank. It was an anaerobic tank with a labyrinthal sewage flow. The tank was divided into 6 chambers. Its bottom was equipped with 3 specially designed funnels. Sludge was removed by a portable pump every 20th day.

Aerobic–anaerobic reactor consisted of:

Anaerobic chamber, whose volume was $V = 31.5\ \mathrm{m}^3$, and the retention time $t = 1.5$ h. The anaerobic chamber was equipped with a paddle mixer ($N_s = 1.2$ kW). Sludge concentration $x = 40$ kg of dry organic matter/m^3.

Denitrification chamber of the volume $V = 67.8\ \mathrm{m}^3$ and sludge concentration $x = 4.0$ kg of dry organic matter/m^3. This chamber was equipped with mixer of a horizontal axis ($N_s = 1.5$ kW).

Nitrification chamber of the volume $V = 170.7\ \mathrm{m}^3$. It was aerated with a compressed air by means of 121 diffusers. The oxygen demand was 410 kg/d, the air quantity $Q_a = 5.65\ \mathrm{m}^3/\mathrm{min}$.

Secondary settling tank. An active volume of the secondary settling tank $V = 74\ \mathrm{m}^3$. The bottom of tank was equipped with a pump recirculating sludge (outer recirculation). The sludge being recirculated was directed to anaerobic chamber, and excessive sludge – to a sludge digestion chamber. The inner recirculation took place between the secondary settling tank and the denitrification chamber.

Blower station. The blower station was equipped with 3 blowers. The capacity of blowers $Q_1 = 3.21\ \mathrm{m}^3/\mathrm{min}$.

Sludge digestion chamber. It was adjacent to the secondary settling tank. The assumed time of digestion $t_f = 75$ days, the storage time $t_{st} = 30$ days. The volume of the sludge-digestion chamber was 243 m^3.

Station of sludge dewatering. The digested sludge was pumped from a sink basin adjacent to the sludge digestion chamber by means of a floodable pump. The quantity of sludge to be dewatered was $Q = 1.52\ \mathrm{m}^3/\mathrm{d}$. Sacks with sludge were stored in a storage yard. The diagram of the sewage treatment plant before modernization is shown in figure 1.

3. TREATMENT PLANT BEFORE MODERNIZATION

The technological unit system was not capable of bringing about the expected efficiency, all the more because the pollutant loads increased. Its inefficiency was due to:

- The use of a primary settling tank with a long retention time and construction making the sludge removal impossible, which led to the sludge hydrolysis resulting in an increase in digestion products in sewage. In the sewage from dairy industry, commercial slaughter houses and meat-processing plants, an intensive digestion and decomposition of proteins took place. This made the wastewater that left the primary settling tank more polluted than crude sewage.

- The fact that the products of hydrolysis caused only an efficient sludge dephosphorization (by 80–85%).
- The fact that the concentration of pollutants in the purified sewage did not comply with the standards, though the removal of organic matter exceeded 90%.
- There was no evidence of the nitrification process.

Table 2

The results of purified waste analysis (June 2001)

Indicators of pollution (mg/dm^3)	Crude sewage (mg/dm^3)	Purified sewage (mg/dm^3)	Standards (mg/dm^3)	Limit exceeding (mg/dm^3)	Removal (%)
COD	1030	125	150	25	89
BOD_5	640	43	30	13	93
Suspended matter	205	17	50	–	91
Nitrogen	109	49	30	19	55
Ammonia nitrogen	83	37	6	31	55
Phosphorus	24	7.9	5	2.9	87

4. MODERNIZATION

A pumping station and a slot sand trap were reconditioned. A slot sand trap was equipped with an aeration system. A new surge tank and a tank for wastewater being delivered from outside were constructed. The primary settling tank was eliminated. It was changed into a pre-denitrification chamber and a sludge stabilization basin. The digestion chamber was changed into a nitrification chamber I°. The nitrification chamber, the denitrification chamber, the anoxic chamber and the secondary settling tank remained unchanged. A 12-sack-filling machine was installed in order to dewater the sludge. When diffusers were covered with sludge whose depth approached 5 m, it was also necessary to increase the inflow of air up to about 12 m^3/min. This was achieved by installing a more powerful (11 kW) blower which allowed increasing the amount of oxygen to about 900 kg/d. In order to ensure a proper course of sewage treatment, oxygen and pH levels in the nitrification chamber were constantly monitored and controlled. The sludge level in the secondary settling tank was also controlled.

5. PLANT AFTER MODERNIZATION

A new technological system and dimensions of its units were based on [1]–[6]. The modernized sewage treatment plant (see figure 2) operates in the technological system described below.

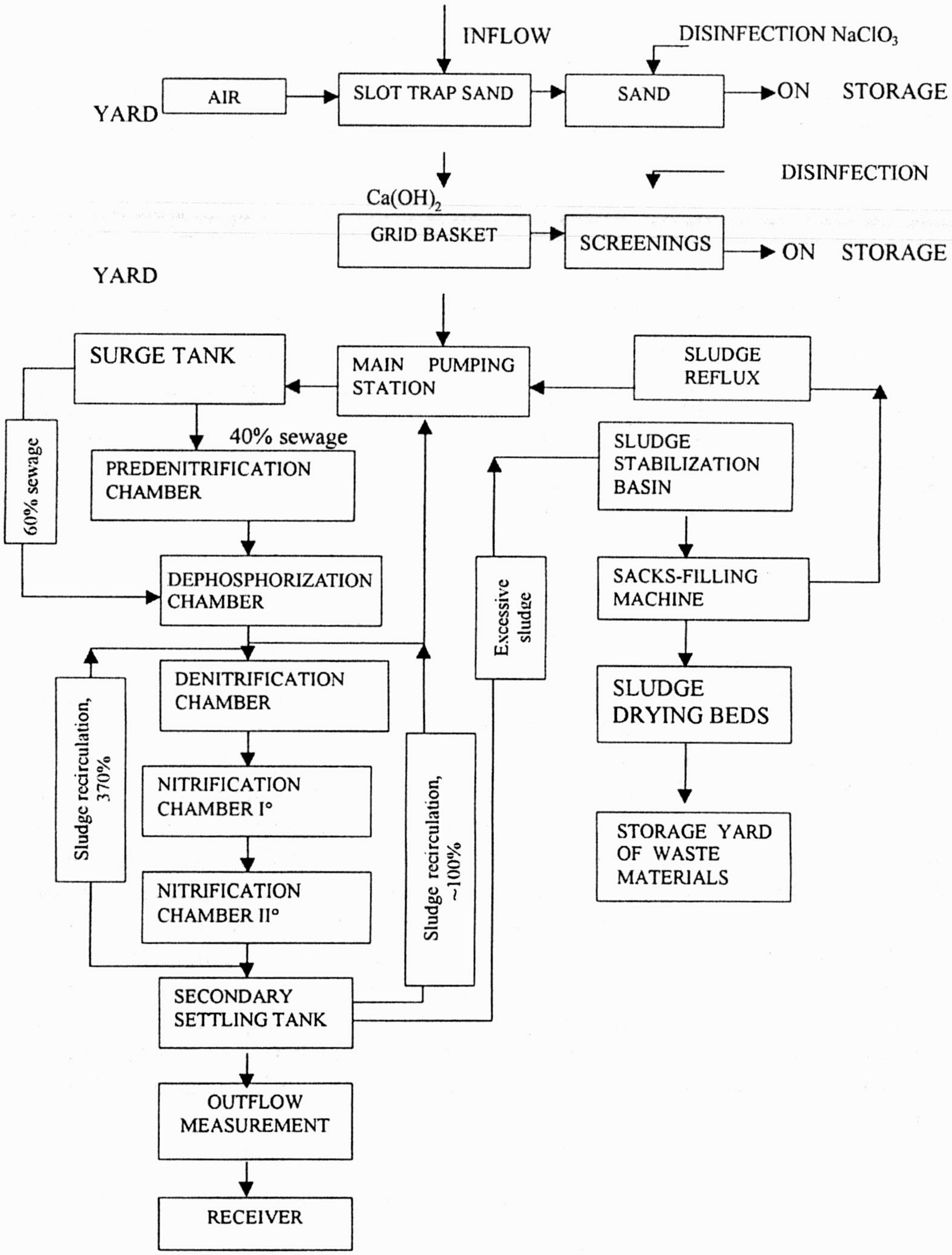

Fig. 2. Block diagram of sewage treatment plant after modernization

5.1. PUMPING STATION

The surface area of the pumping station is 9.28 m^2, and its functional height, 1.6 m.

The pumping station was designed to pump sewage into the surge tank. A necessary height of sewage raising is 10.6 m. The delivery of the pumps should be higher than a maximum hourly water demand of 17.66 dm^3/s, i.e. 63.56 m^3/h. Two cooperating pumps were used, and their combined capacity exceeded a maximum hourly water demand.

5.2. SURGE TANK

The surge tank was made of reinforced concrete. Its volume is 180 m^3, the total height, 5.5 m, and the functional height, 5.0 m. It was equipped with a mixer and metering pumps whose delivery approached a mean daily water demand $Q_{md} = 15.5$ m^3/h. Two pumps of 2.2 kW power, the raising height of 8 m and the capacity $Q = 16$ m^3/h were installed. A tapping runner was installed inside the surge tank at the height $h = 4.5$ m. The floating fraction is carried away by the tapping runner into the sludge stabilization basin.

5.3. PLACE WHERE SEWAGE IS DELIVERED BY WASTE REMOVING CARS

A 25 m^3 tank allows not only gathering wastes carried by water cart but also their even and steady disposal. The tank capacity limits naturally the volume of sewage that can be delivered and dropped off daily. The tank has the following parameters: total capacity of 25 m^3 and functional height of 2.0 m. The sewage is gravitationally discharged into sewage system. The tank is equipped with a sluice valve.

5.4. UNIT OF BIOLOGICAL TREATMENT AND BASIN OF SLUDGE STABILIZATION

A unit of biological treatment consists of a pre-denitrification chamber, an anaerobic chamber, two nitrification chambers, a secondary settling tank and a sludge stabilization basin. The quantities accepted in the project:

Mean daily flow, $Q_{md} = 315$ $m^3/d = 13.12$ $m^3/h = 3.64$ dm^3/s.
Max daily flow, $Q_{d\max} = 365.4$ $m^3/d = 15.23$ $m^3/h = 4.23$ dm^3/s.
Max hourly flow, $Q_{h\max} = 37.3$ $m^3/h = 10.36$ dm^3/s.
Mean hourly flow (in the day), $Q_{\mathrm{calc}}' = 21.0$ $m^3/h = 5.83$ dm^3/s.
Mean hourly flow(at night), $Q_{\mathrm{calc}} = 9.0$ $m^3/h = 2.5$ dm^3/s.

For further calculation real concentration of pollutants and unit loads were accepted (table 1). PE was set at 7450 for BOD, and 2927 for suspended matter.

Pre-denitrification chamber. The pre-denitrification chamber separated from one of the chambers of the primary settling tank was equipped with one mixer. The dimensions of the chamber are 1.9×3.8 m and its functional height is 5.0 m. A total height is 5.5 m. The baffle plates of a tank were extended to its bottom. The pre-denitrification chamber obtained in such a way has the capacity of 36 m^3. This capacity guarantees an adequate time of sewage retention for 40% of crude sewage; and recirculated sludge from the secondary settling tank is directed to the pre-denitrification chamber. Recirculation of sludge approaches 90–100%.

Anaerobic chamber. The retention time was set at 1.5 h, with a mean daily water demand taken into account. The capacity of the anaerobic chamber is 33 m^3. 60% of the sewage supplied to anaerobic chamber comes from the secondary settling tank. The concentration of sludge was 4.0 kg of dry organic matter/m^3.

A mixer continually mixing the sewage was installed on a supporting construction which prevents the mixer from making horizontal and vertical movements.

Sewage leaves an anaerobic chamber through 0.3×0.4 m holes in the wall that separates the anaerobic chamber from denitrification chamber.

Denitirfication chamber. The capacity of the denitrification chamber was calculated at a minimum temperature of 12 °C and sludge concentration of 4.0 kg of dry organic matter/m^3. The denitrification chamber is a covered chamber, and the walls of the reactor are insulated by means of soil.

Crude wastewater whose BOD_5 is equal to 1420 O_2/m^3 requires a 65 m^3 denitrification chamber which corresponds to 4.95-hour time of flow. Since 5-hour time of flow was accepted, the capacity of the chamber was 65.6 m^3, and its surface area, 13.96 m^2.

Nitrification chamber. The pollutant loads directed into a unit of biological purification have to be kept in a sludge tank whose volume approaches 428 m^3. This volume can be achieved as a result of raising the level of sewage to 5.0 m and adapting the whole digestion chamber to an activated sludge chamber. Due to this solution the aeration chamber I° has the following dimensions: 5.8×8.4×5.0 m, which gives a capacity of 243.6 m^3. The dimensions of the aeration chamber II° are: $6.4\times5.8\times5.0\ m = 185.6\ m^3$.

A total capacity of the two chambers is $185.6 + 243.6 = 429.2\ m^3$.

The parameters of the working aeration chambers are as follows:

- Sludge reserve, $z = 3200$ kg.
- Sludge concentration, $X = 6\ kg/m^3$.
- Sludge age (sludge residence time), SRT = 7 days.
- Sludge index, $I = 100$.
- BOD_5 loading = 0.14 kg of BOD_5/kg of dry organic matter.
- The ratio of suspended matter to BOD_5 is 0.44.

- Growth of excessive sludge in aeration chamber is 0.9 kg/kg of BOD_5.
- The quantity of sludge directed to stabilization basin approaches 390 kg/d, i.e. 13 m^3 at 3% concentration of sludge.

Aeration is carried out by means of elastomer disks consisting of 11 segments, each comprising 11 diffusers. The oxygen demand is 900 kg of O_2/d. The factor of oxygen utilization from the air is 0.25 (for $H = 2.5$ m), and the oxygen content in the air is 0.28 g/m^3. Two blowers of the DR101-6,4-T type produced in Spomasz-Ostrów Wielkopolski supplied the diffusers with air. The diffuser parameters are as follows: $Q = 3.21$ m^3/min, $n = 3285$, $N = 5.5$ kW, $m = 255.7$ kg, $V = 380$ V. An additional blower of the DR 102T-7,6 type is also used and its parameters are: $Q = 5.7$ m^3/min, $n = 3300$, $N = 11$ kW. The blowers are equipped with a sound insulation shield. The blower station is covered.

5.5. SECONDARY SETTLING TANK

A 3.5-hour retention time was accepted. It was calculated on the basis of a mean hourly water demand, i.e. 21 m^3/h. The capacity, height and width of the settling tank are 73.5 m^3, 4.9 m and 5.8 m, respectively. This tank is one of the elements of the anaerobic–aerobic reactor. Sewage leaves nitrification chamber and is directed to secondary settling tank. A real capacity of the secondary settling tank is 74.02 m^3.

Sludge recirculation (it leaves the bottom of the tank and is directed to the anaerobic tank) is forced by a floodable pump, whose raising height and working capacity are 4.0 m and 10 dm^3/s, respectively.

6. SLUDGE HANDLING

6.1 SLUDGE STABILIZATION BASIN

A primary settling tank was changed into sludge stabilization basin. This basin was provided with 49 air diffusers – seven diffusers in the first part of the basin, 21 in the second part, and 21 in the third part.

- The quantity of sludge inflow to the sludge stabilization basin is 390 kg/d.
- The SRT (inflow of activate sludge) is 10 days.
- The disposal capacity is about 390 kg of dry organic matter per day, provided that sludge concentration is 3%.

Sludge has to be kept inside the basin for 16.5 days. The stabilisation SRT is 28 days, while the required age is 25 days. After that period the sludge is totally stabilized and is no longer noxious for the environment. The mass of sludge after stabilization process is 330 kg of dry organic matter/day. The sludge is collected in sacks. Therefore, a 12-sack filling machine is used. In order to dehydrate the sludge collected in sacks, they are left for about 20 hours. The dehydrated sludge is stored for about 3 months on the yard whose surface is hardened, which allows its 65–70% dehydration. The sludge for the dehydratation is scooped by a floodable pump, which is situated in the last part of sludge stabilization basin. That part of the basin works like a sludge gravity thickener. A drain pipe was installed on a pressure conduit. It controls the sludge flow (5 m^3/h) and allows an appropriate dosage of polyelectrolyte.

The floor drain is installed inside the dehydration unit. This floor drain enables the reflux to leave a dehydratation station. The reflux is directed to a pumping station, and then to treatment processes.

7. MODERNIZATION OF SEWAGE TREATMENT PLANT ALLOWING IT TO COPE WITH POSSIBLE ENVIRONMENTAL THREATS

The sewage treatment plant under discussion is designed in a continuous flow mode, which means that each disturbance in its operation will be discovered in 2 days. If information about the disturbance in the treatment processes is obtained early enough, then the sewage with an excessive pollutant loads will be accumulated in a surge tank. Over the time necessary for treating the sewage the plant will be working without the surge tank. Though the effects of sewage purification will be worse, the parameters of purified sewage comply with standards.

8. SUMMARY

A modernization of sewage treatment plant described above allows us to increase the effectiveness of removing both organic and biogenic compounds. Table 3 presents the results of sewage analyses from April 2003.

Table 3

Analyses of sewage after treatment (April 2003)

Indicators of pollution	Crude sewage (mg/dm^3)	Purified sewage (mg/dm^3)	Standards (mg/dm^3)	Limit exceeding (mg/dm^3)	Removal (%)
COD	3605	58	150	–	98
BOD_5	1420	12	30	–	99
Suspended matter	620	14	50	–	97.7
Nitrogen	120	10	30	–	91.6
Ammonia nitrogen	89	0.5	6	–	99
Phosphorus	27	3	5	–	88

Due to implementation of surge tank the qualities of crude sewage and sewage after treatment are very stable and ensure that the treatment plant is steadily loaded throughout a day. This solution could form the basis for future attempts to reduce the blow factors f_c and f_n while calculating the oxygen demand – a contention put forward also by KAYSER [7].

Stable operation of a treatment plant has led to an efficient removal of biogenic compounds at a relativity high activated sludge loading and an appropriate sludge index.

The modernization process allows an effective control of working parameters, not only in terms of sewage treatment, but also in terms of the reduction of costs, especially the cost of electricity.

A very important contribution to the effective work of the treatment plant was the fact that the sewage temperature has never dropped below 14 °C. The way in which the sewage treatment processes were carried out ensured a high level of treatment and minimized cases of possible environmental threats.

9. CONCLUSIONS

1. In the author's opinion, an advanced treatment technology has still a great potential for facilitating sewage treatment processes as well as reducing their costs.

2. It is possible to remove all nitrogen and phosphorus at a relatively high loading and a small safety factor, provided that technological principles, which have to be chosen very carefully, are strictly fulfilled.

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ZINTEGROWANE USUWANIE WĘGLA, AZOTU I FOSFORU W ZMODERNIZOWANEJ OCZYSZCZALNI ŚCIEKÓW W KOBYLCU

Omówiono efekty modernizacji oczyszczalni ścieków przemysłowych dla 7450 RLM. Scharakteryzowano oczyszczalnię ścieków przed modernizacją. Przedstawiono jej układ technologiczny, dane przyjęte do projektowania, wykazano potrzebę zwiększenia skuteczności usuwania węgla, azotu i fosforu. Modernizacja oczyszczalni polegała przede wszystkim na wyeliminowaniu osadnika wstępnego, rezygnacji z komory fermentacji osadów w kierunku tlenowej stabilizacji, stworzeniu warunków do intensywnej nitryfikacji, denitryfikacji oraz biologicznej defosfatacji. Przedstawiono nowy układ technologiczny, omówiono poszczególne obiekty. Wykazano lepsze efekty usuwania związków biogennych po modernizacji oczyszczalni.