

EVALUATION OF THE OPERATION OF THE SEWAGE TREATMENT PLANT „KUJAWY” IN CRACOW

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Summary. This paper presents the evaluation of the operation of the sewage treatment plant located in Cracow, serving its 250-thousand district – Nowa Huta. The results were analyzed based on raw and treated sewage examinations carried out in 2009–2011. Five main pollution indicators were analyzed, i.e.: BOD₅, COD_{Cr}, total suspended solids, total nitrogen and total phosphorus. The average reduction efficiency of these indicators in the analyzed period reached 99.0%, 96.0%, 98.2%, 69.8% and 94.5%, respectively.

Key words: sewage treatment plant, pollution reduction efficiency

INTRODUCTION

After the Nowa Huta district had been built in the 50s of the 20th century, two separate sewer systems began to operate in Cracow. To support the youngest district of Cracow, the Sewage Treatment Plant „Kujawy” was established east of the residential areas in the Pleszów village and south of the metallurgical plant (currently ArcelorMittal Poland JSC).

As the so-called Cracow conurbation, integrating the neighboring towns into one body (i.e. Wieliczka, Skawina, Krzeszowice) was initiated in those days, the efficiency of the Nowa Huta treatment plant was designed on a grand scale. The oversized treatment plant currently uses only 50–60% of its capacity.

The treatment plant in Płaszów, with a designed capacity of 132,000 m³·d⁻¹ is the major treatment plant for Cracow, receiving two thirds of the produced sewage. Despite a recently completed project involving EU funds „Sewage treatment plant Płaszów II in Cracow”, there are still limitations to the functioning of this sewerage system [Biedrzycka 2009]. In this situation, the planned construction of the collector for Lower Vistula Terrace, which will connect the currently separated sewerage systems for Cracow, will allow to transfer sewage from the catchment of the „Płaszów” treatment plant to the „Kujawy” treatment

plant, and thus to optimize the operation of both plants. With this investment, the sewerage system will be established for the housing estates along the route of the LVT collector. This includes the collection of sewage from neighboring municipalities, i.e.: Zielonki, Wielka Wieś, Igołomia-Wawrzeńczyce, Michałowice, Kocmyrzów-Luborzyca [Long-term plan ... 2011].

AIM, SCOPE AND METHODOLOGY OF RESEARCH

The aim of this study was to evaluate the operation of the mechanical-biological sewage treatment plant „Kujawy” in Cracow. The evaluation was based on the determined parameters of the object's operation, i.e. the efficiency of organic pollutants removal from sewage (expressed as indexes: BOD₅ and COD_{Cr}) as well as the removal of total suspended solids and biogenic compounds (expressed as total nitrogen and total phosphorus). Additionally, the amount of sewage flowing into the treatment plant was determined in each month of the analyzed period.

The Sewage Treatment Plant „Kujawy” was put into operation in 1999 as a mechanical-biological treatment plant with chemical support for the removal of phosphorus. Sewage flowing into the treatment plant is subjected to mechanical treatment by removing floating pollutants and coarse debris on rare grate, precipitation of mineral suspension and fat – on aerated sand trap, separation of solids – on dense grate, and then removal of settleable solids – in preliminary settling tank.

The stage of biological treatment was performed using a flow reactor, in which the process of low-loaded activated sludge according to the modified BARDENPHO technology is carried out. In order to deoxygenate and remove the contained nitrates, the process of predenitrification of recirculated sludge was implemented through the external recirculation. The process of primary sludge hydrolysis for the production of volatile fatty acids was intended to be carried out under the conditions of organic carbon deficit in order to support the biological removal of biogenic compounds. Moreover, the possibility of additional phosphorus precipitation (initial and final simultaneous – with the application of ferrous sulfate as coagulant) was designed. Secondary settling tanks were designed for the retention of excessive sludge after the biological reactor [Juda 2007].

The analyzed treatment plant receives municipal sewage, that is the mixture of domestic and industrial sewage together with rainwater. Sewage treated by the „Kujawy” Treatment Plant flows in gravitationally and when the level is high, it is pumped by a partially open collector and discharged below the Przewóz barrage in km 94+000 to the Vistula River.

According to the current water-law permission for the discussed treatment plant, the average daily efficiency of the sewage treatment plant „Kujawy” in the dry period is 80,000 m³ · d⁻¹, while in the rainy period and during snowmelt pe-

riod it is $250,000 \text{ m}^3 \cdot \text{d}^{-1}$. In 2009–2011 the treatment plant received on average $55.33 \text{ m}^3 \cdot \text{d}^{-1}$ of sewage and the highest daily sewage inflow was $77.44 \text{ m}^3 \cdot \text{d}^{-1}$ and did not exceed the permissible value.

The operation of the „Kujawy” treatment plant was assessed based on the results of raw and treated sewage analyses, performed by the Laboratory of Sewage Analysis for the STP „Kujawy”. The samples were collected 2–3 times per month from January 1st 2009 to December 31st 2011 and then the following indexes were determined: BOD₅ using electrochemical method, COD_{Cr} and total phosphorus – spectrophotometrically, total suspended solids – by the gravimetric method and total nitrogen – from the calculation.

The results were analyzed statistically. Minimum, maximum, arithmetic mean, median, standard deviation and coefficient of variation were calculated for the mentioned indexes. The reliability of the treatment plant was evaluated based on the determined reliability coefficient [Andraka 1997] and the technological performance indicator P_{sw} [Rak 1997].

RESULTS AND DISCUSSION

The Figure 1 presents the concentration of pollutants in raw and treated sewage and the resulting effect of the examined pollution indexes removal.

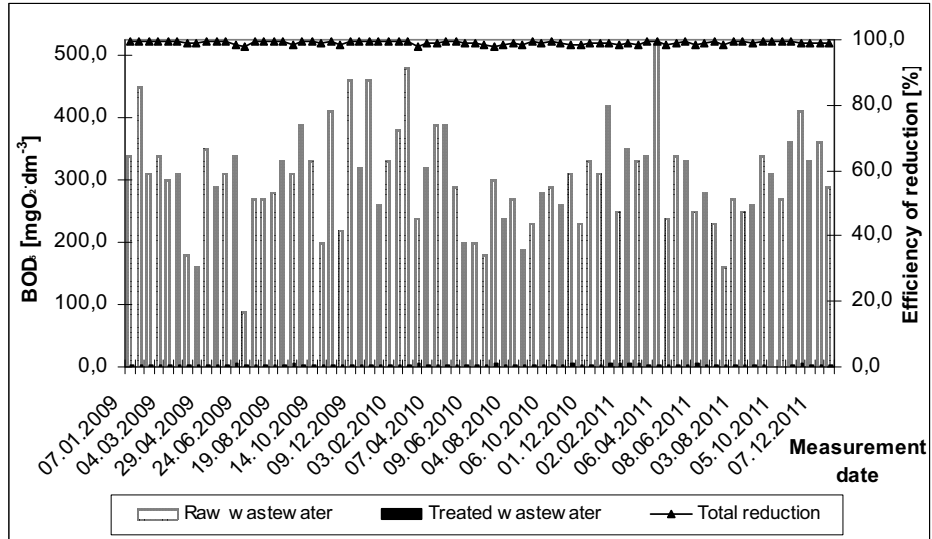
Data from the Figure 1a indicate that the mean value of BOD₅ in the examined period in raw sewage reached $302.8 \text{ mg O}_2 \cdot \text{dm}^{-3}$, and its changes ranged from 90.0 to $520.0 \text{ mg O}_2 \cdot \text{dm}^{-3}$. BOD₅ values in treated sewage ranged from 1.2 to $5.6 \text{ mg O}_2 \cdot \text{dm}^{-3}$ and the mean value of this parameter was $2.7 \text{ mg O}_2 \cdot \text{dm}^{-3}$. The BOD₅ value in the analyzed period remained at much lower level compared to the limit value given by the current water-law permission ($15 \text{ mg O}_2 \cdot \text{dm}^{-3}$). The obtained results of removal efficiency fall within the range of 97.7–99.6% and their average value was 99.0%.

The mean COD_{cr} value in raw sewage was $659.0 \text{ mg O}_2 \cdot \text{dm}^{-3}$ (Fig. 1b), while its values ranged from 199.0 to $1180.0 \text{ mg O}_2 \cdot \text{dm}^{-3}$. On the other hand, treated sewage was characterized by COD_{cr} values ranging from 14.0 to $73.8 \text{ mg O}_2 \cdot \text{dm}^{-3}$ and not exceeding the limit of $125 \text{ mg O}_2 \cdot \text{dm}^{-3}$. The mean value of the discussed index was $25.1 \text{ mg O}_2 \cdot \text{dm}^{-3}$. The COD_{cr} removal efficiency ranged from 91.4 to 98.0%, while its mean value was 96.0%.

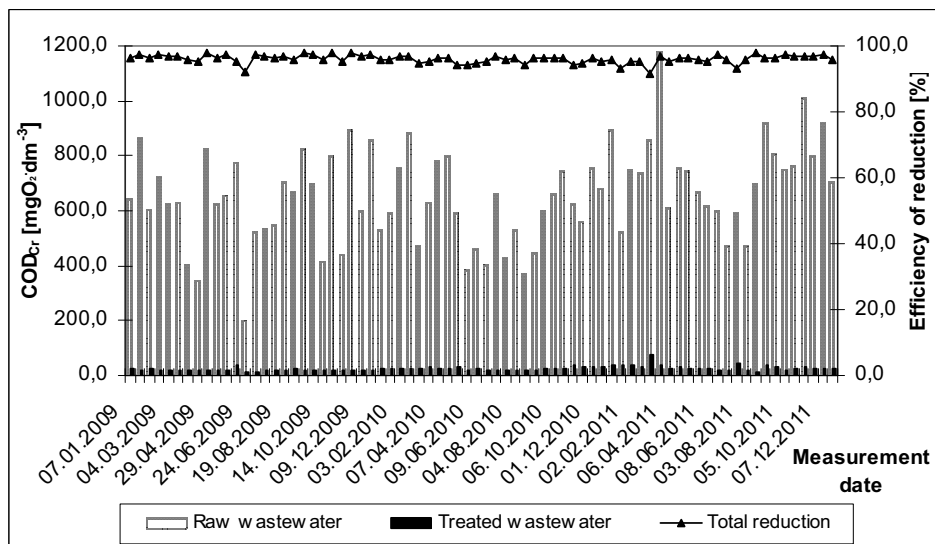
The Figure 1c shows that the concentration of total suspended solids in raw sewage ranged from 140.0 to $590.0 \text{ mg} \cdot \text{dm}^{-3}$ and the mean value was $292.4 \text{ mg} \cdot \text{dm}^{-3}$. Treated sewage was characterized by the concentration of total suspended solids ranging from 2.0 to $12.0 \text{ mg} \cdot \text{dm}^{-3}$ (mean $5.0 \text{ mg} \cdot \text{dm}^{-3}$). In the analyzed period there were no transgressions of the permissible concentration of total suspended solids, defined by the current water-law permission ($35 \text{ mg} \cdot \text{dm}^{-3}$).

It may be concluded that the removal efficiency of total suspended solids was high (from 95.5 to 99.5%), while the mean efficiency reached 98.2%.

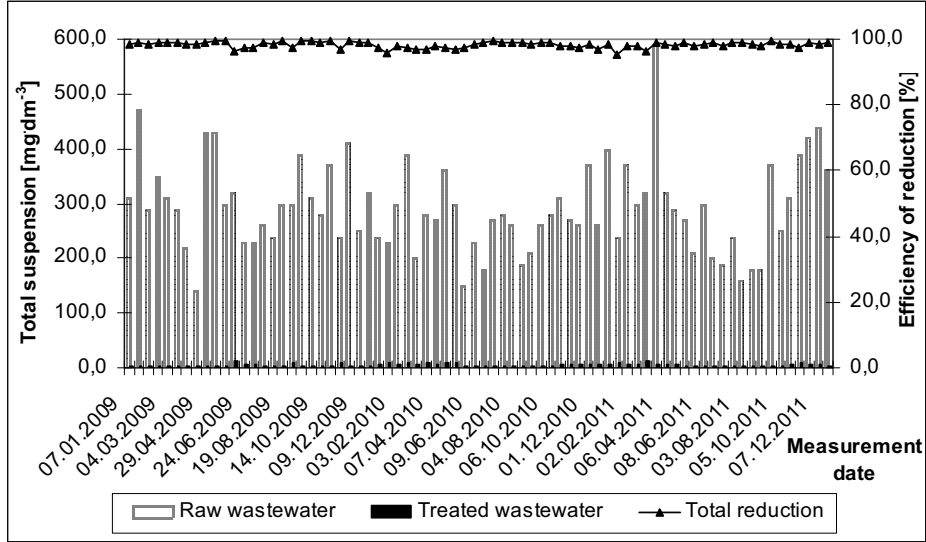
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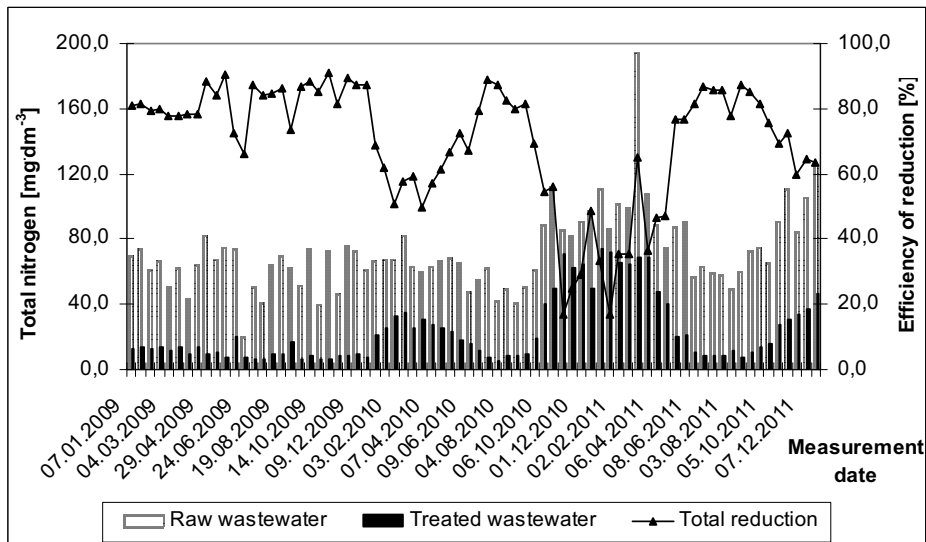
b)



c)



d)



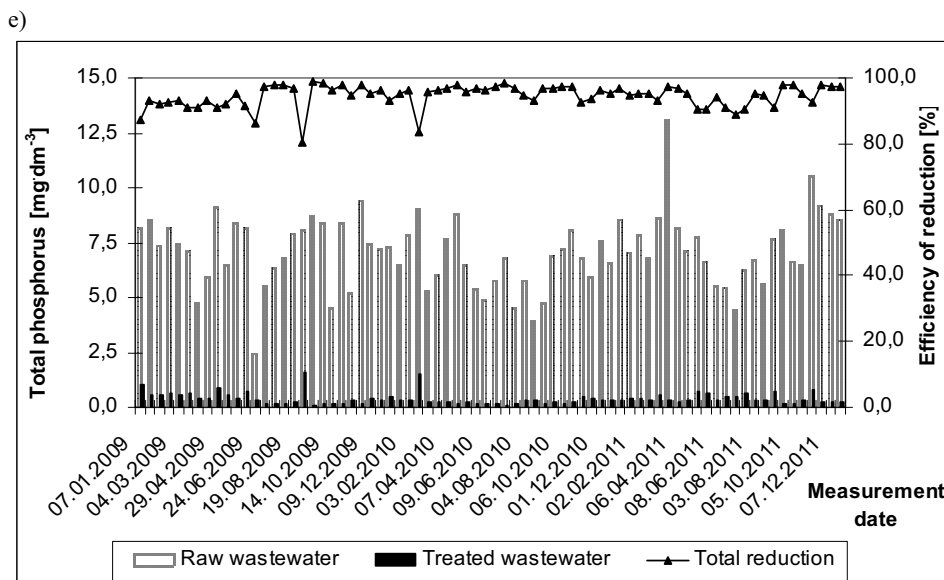


Fig. 1. Summary of BOD₅ (a), COD_{Cr} (b), total suspension (c), total nitrogen (d) and total phosphorus (e) in raw and treated wastewater and efficiency of their reduction

In the discussed period, the total nitrogen content in raw sewage (Fig. 1d) ranged from 20.5 to 195.0 mg · dm⁻³ (mean 72.5 mg · dm⁻³). The total nitrogen concentration in treated sewage ranged from 5.3 to 74.1 mg · dm⁻³. The maximum concentration, recorded in January 2011 exceeded three times the limit value of 22.5 mg · dm⁻³. The mean value of the described parameter in treated sewage was about 23.9 mg · dm⁻³. In the analyzed period, only 47 out of 74 samples collected from the effluent did not exceed the admissible value.

The mean removal efficiency of biogenic compounds, expressed as total nitrogen, was 69.8%, while the values of the discussed index ranged from 16.9 to 91.1%.

In the case of the second biogenic index of raw sewage – total phosphorus – minimum and maximum values were 2.45 and 13.10 mg · dm⁻³, respectively (Fig. 1e), and the mean value was 7.10 mg · dm⁻³. The concentration of total phosphorus in treated sewage was 0.11–1.58 mg · dm⁻³. The maximum value, recorded in September 2009, exceeded the permissible value by 5%. The mean concentration of total phosphorus in treated sewage was 0.38 mg · dm⁻³.

The efficiency of total phosphorus removal ranged between 80.6 and 98.7% (mean 94.5%).

The Table 1 evaluates the operation of the „Kujawy” treatment plant and compares the real values of pollution indexes in the effluent in 2009–2011 with the permissible values.

The conducted analysis revealed high operation reliability of the examined process line in the elimination of organic pollutants from sewage, expressed as BOD₅ and COD_{Cr} indexes (reliability coefficient was 0.18 and 0.20, respectively).

Table 1. Permissible and real values of pollution indexes in treated sewage in 2005–2010 and evaluation of the operation of the sewage treatment plant „Kujawy” in 2009–2011

Parameter	Permissible value in the effluent X_{dop} , $mg \cdot dm^{-3}$	Real value in the effluent, $mg \cdot dm^{-3}$			Coefficient of variation	Coefficients of treatment plant operation	
		average X_{sr}	min. X_{min}	max X_{max}		reliability coefficient WN^*	technolog. perform. P_{sw}^{**}
BOD ₅	15	2.7	1.2	5.6	0.43	0.18	0.99
COD _{Cr}	125	25.1	14.0	73.8	0.34	0.20	0.99
Total suspended solids	35	5.0	2,0	12.0	0.53	0.14	0.99
Total nitrogen	22.5	23.9	5.3	74.1	0.84	1.06	0.63
Total phosphorus	1.5	0.38	0.11	1.58	0.74	0.25	0.97

* $WN = X_{sr}/X_{dop}$; X_{sr} – mean value in the effluent from the treatment plant, X_{dop} – permissible value

** $P_{sw} = n/N + 1$; n – number of results for a given pollution index according to X_{dop} , N – number of all results

Low values of the reliability coefficient were also recorded in the case of total suspended solids ($WN = 0.14$) and total phosphorus ($WN = 0.25$), although those parameters were characterized by higher variation (coefficient of variation was 0.53 and 0.74, respectively).

The highest value of the coefficient of reliability WN was recorded for total nitrogen ($WN = 1.06$), which was also characterized by the highest coefficient of variation, amounting to 0.84.

The designated technological performance indicators ($P_{sw} = 0.99$ for BOD₅, COD_{Cr} and total suspended solids; $P_{sw} = 0.97$ for total phosphorus) demonstrate high operation efficiency of the „Kujawy” treatment plant in 2009–2011, both in the mechanical part and in the case of organic pollutants’ removal and elimination of phosphorus.

Low value of technological performance indicator for total nitrogen $P_{sw} = 0.63$ clearly shows that the requirements stated by the current water-law permission were not fulfilled.

CONCLUSIONS

The following conclusions were drawn based on the conducted analysis of results:

– Mean efficiency of BOD₅ and COD_{Cr} removal was high and amounted to 99.0% and 96.0%, respectively. Mean values of the discussed indexes in the effluent were about five times lower than the permissible values.

– Mean efficiency of the total suspended solids removal in the sewage treatment plant was 98.2%, which is a very good result and demonstrates proper operation of the treatment plant in its mechanical part. There were no transgressions of the permissible value.

- Mean efficiency of removal of the total nitrogen concentration in the treatment plant was 69.8%. Almost 40% of the analyzed samples did not fulfill the requirements.
- Mean efficiency of removal of the total phosphorus concentration in the treatment plant reached high level of 94.5%. During the three discussed years, the permissible value was exceeded once.
- High values of technological performance indicate a high likelihood of adherence of the organic compounds content and total suspended solids in the effluent from the Sewage Treatment Plant „Kujawy” to the limits specified by the current water-law permission.
- The calculated values of reliability coefficients for biogenic compounds in the relevant period confirmed the effective elimination of total phosphorus, while pointing to incorrect operation of the treatment plant in the case of total nitrogen removal. The Municipal Water Supply and Sewerage Plant JSC in Cracow planned to modernize the facilities of the Sewage Treatment Plant „Kujawy” for 2011–2017 to increase the efficiency of nitrogen removal [Long-term plan ... 2011].

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OCENA FUNKCJONOWANIA ZAKŁADU OCZYSZCZANIA ŚCIEKÓW „KUJAWY” W KRAKOWIE

Streszczenie. W artykule przedstawiono ocenę działania oczyszczalni ścieków zlokalizowanej w Krakowie, obsługującej jego 250-tysięczną dzielnicę – Nową Hutę. Analizy wyników dokonano w oparciu o badania ścieków surowych i oczyszczonych w latach 2009–2011. Analizie poddano pięć podstawowych wskaźników zanieczyszczeń: BZT₅, ChZT_{Cr}, zawiesinę ogólną, azot ogólny oraz fosfor ogólny. Średnia skuteczność zmniejszenia tych wskaźników w analizowanym okresie wyniosła odpowiednio 99,0%, 96,0%, 98,2%, 69,8% oraz 94,5%.

Słowa kluczowe: oczyszczalnia ścieków, skuteczność zmniejszania zanieczyszczeń