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IMPACT OF EXTRANEOUS WATERS ON THE PROPORTION OF SEWAGE POLLUTION INDICESREGARDING ITS BIOLOGICAL TREATMENT

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Summary

The research aimed to learn if and to what extent extraneous waters, occasionally flowing into sanitary sewer system during atmospheric precipitation, change proportions of selected pollution indices which are significant regarding biological sewage treatment. The following proportions between pollution indices should be maintained in the sewage subjected to biological treatment process: $COD:BOD_5 \leq 1.8$; $BOD_5:N \geq 4.0$, $BOD_5:P \geq 25$; $COD:P \geq 3.6$. Investigations conducted in two sewer systems located in the Małopolskie voivodeship revealed that extraneous waters infiltrating the intercepting sewers during wet weather negatively affect all proportions between pollution indices. Increasing amount of extraneous waters in sewer systems caused the greatest changes of $BOD_5:N$ and $BOD_5:P$ proportions. On the basis of conducted research it was found that considerable quantities of nitrogen and phosphorus compounds are supplied to the sewer system with extraneous waters, which in biological denitrification and dephosphatation processes may lead to a deficit of organic compounds causing a necessity to provide an external source of carbon for the reactor chambers, such as methanol, ethanol, acetic acid, glucose or others. During the conducted investigations it was demonstrated that extraneous waters in interceptors cause not only sewage dilution, but also significantly change its chemical composition.

Keywords: sewage, sewer system, extraneous waters, denitrification, dephosphatation

INTRODUCTION

At a time of climatic changes resulting in the raised temperature, nobody must be assured how precious is water which may be used for water supply systems. The quality of surface and underground waters, which may be sources of potable water, are significantly affected especially by anthropogenic pollutants, whose main sources remain untreated or insufficiently treated domestic or industrial sewage. Regarding protection of precious water resources, it is important that both already existing and newly constructed sewage removal and disposal systems were reliable (Kalenik and Siwiec, 2013).

One of the factors negatively affecting sewer system functioning, particularly operation of sewage treatment plants, are extraneous waters (Cupak and Wałęga, 2011;Kaczor, 2012b;Pawełek and Cieślak, 2014). These are most frequently rainwaters or meltwaters entering the sewer system through leakage of tops or openings in catch pit manholes (Pecher, 1999; Lucas, 2003;Kaczor, 2009). Extraneous waters comprise also the outflows from roof gutters and yard inlets, drainage systems of building foundations or property areas, but also streams of waters drained during construction, renovation or cleaning works, accidently or mistakenly discharged into the sewer system.

In the sanitary sewer system extraneous waters usually contribute to manyfold increase in sewage flow rate resulting in intercepting sewer filling to capacity (gravity sewer system operation under pressure), sewage impoundment in catch pits and in the extreme cases its outflow through floor drains in the basements or in the underground technical infrastructure facilities (Pecher, 1999).

Extraneous waters especially negatively impact on the functioning of sewage treatment plants. It is evidenced mainly as periodical hydraulic overload of the technological facilities of the treatment plants, which in consequence negatively affects the quality of sewage discharged to the receiver (Kaczor and Bergel, 2008). Extraneous waters cause a dilution of raw sewage and during the snowmelt period their cooling, which has a unfavourable effect on biological processes connected with biogenic compounds removal by means of activated sludge method (Siwiec and Dylewski, 2004; Wałęga and Kaczor, 2012; Kaczor and Bugajski, 2012;Kaczor, 2012a; Kaczor, 2012b).

The references concerning extraneous water impact on functioning of sewage treatment plants usually assume that these waters do not contain any important pollutants and only dilute raw sewage (Strategien…, 2005). However, field studies conducted for many years at the Department of Sanitary Engineering and Water Management, at the University of Agriculture in Krakow show that such assumption is not always in tune with reality. It was noticed that in rural and suburban settlements, where considerable areas are covered with vegetation, great amounts of various suspensions and other pollutants washed off the surface of the ground and streets are inflowing with extraneous waters through the openings in the catch pit manholes. Therefore, a research thesis may be formulated, that extraneous waters may impact on the chemical composition of raw sewage, particularly on the values of some pollution indices. Changes of these values, in the first place the proportions of these values, may cause that the sewage would be unsatisfactorily cleaned in biological processes. It applies particularly to biogenic compounds. Regarding the potential biological sewage treatment using activated sludge method, the most important are the following proportions of pollution indices (Barnard, 2000;Sadecka, 2010;Dymaczewski, 2011):

$COD:BOD_5 \leq 1.8$ (good organic carbon assimilation criterion),

$BOD_5:N \geq 4.0$ (efficient denitrificatin criterion),

$BOD_5:P \geq 25$ (efficient dephosphatation criterion),

$COD:P \geq 36$ (adequate organic carbon quantity in dephosphatation chamber criterion)

Obviously, the final effect of sewage treatment is affected by many other factors, unrelated with the raw sewage composition. However, in numerous projects and research papers, initial analysis of the above mentioned proportions of pollution indices values gives some idea and allows to predict the course of sewage biological treatment by activated sludge. In order to verify the stated thesis, research was conducted in two selected sewer systems occasionally exposed to extraneous waters inflow during heavy rains.

The cognitive aim of conducted research was learning if and to what extent extraneous waters, occasionally penetrating sanitary sewer, change proportions of selected pollution indices values, important in respect of biological sewage treatment.

METHODS OF RESEARCH

48 samples of raw sewage were collected during the field studies conducted in 2011-2014. Sewage was sampled from the outlets of intercepting sewers in the area of the analysed treatment plants before grating chambers. Sewage collection for analyses was conducted during rainless (dry weather)and during heavy precipitations, i.e. in wet weather.

The 24-hour period was considered rainless weather if no precipitation occurred during it or over five preceding days, or a daily rainfall did not exceed 1mm. All days on which precipitation of more than 1mm occurred were classified as wet weather.

The following pollution indices were assessed in the collected sewage samples: BOD_5, COD, total suspended solids, total nitrogen and total phosphorus. Individual indices were determined by means of referential methods at the laboratory of Water and Sewage at the Department of Sanitary Engineering, University of Agriculture in Krakow.

Measurements of daily sewage flows were conducted in the area of the analysed treatment plants by means of ultrasonic probes of level installed above the triangular weir.

Daily precipitations measured in the area of the analysed treatment plants by means of tipping buckets coupled with impulse recorders were used for the analyses.

Daily inflow of extraneous waters to the sewer system was determined as a difference between daily sewage flow during wet weather and mean daily sewage flow during rainless (dry) weather. Daily inflows of extraneous waters to the sewer system were expressed as their proportion or additionto daily flows (Pecher, 1999). Extraneous water share (*UWP*) in the daily inflow to the sewer system may be computed using the following formula:

$$UWP = \frac{Q_{dp}}{Q_d} \cdot 100 \tag{1}$$

where:

Q_{dp} – daily inflow of extraneous waters to the sewer system [$m^3 \cdot d^{-1}$],

Q_d – total daily inflow of sewage and extraneous waters to the sewer system [$m^3 \cdot d^{-1}$].

Extraneous waters addition of (*DWP)* to the daily inflow to the sewer system is calculated using the following formula:

$$DWP = \frac{Q_{dp}}{Q_{db}} \cdot 100 \tag{2}$$

where:

Q_{db} – daily inflow of sewage to the sewer system during rainless weather [$m^3 \cdot d^{-1}$].

For each day, on which sewage samples were collected, value of the share and addition of extraneous waters were computed in the daily sewage flows.

DESCRIPTION OF THE RESEARCHED OBJECT

Sewage flows and their pollutant concentrations in two selected sewer systems located in the Małopolska voivodeship were analysed as a part of the project. The researched facilities are situated 16 and 27 km from Kraków.

The first facility, marked “A” in the paper, is a 15.2 km long sewer system (the length without house drains) constructed of porcelain pipes with diameters of 200, 250, 300, 350 and 400 mm. The sewer system is 16 years old. 455 buildings inhabited by 2050 people are connected to the sewer. Sewage from this sewer system is discharged to the mechanical-biological sewage treatment plant with hydraulic throughput of 563 $m^3 \cdot d^{-1}$.

The other researched object, marked "B" in the paper is a sewer network, 29 km long (without the house drains), constructed of PCV pipes with the diameters of 200, 250, 300, 350 and 400 mm. 790 households, inhabited by 3160 inhabitants, are connected to the sewer system. Sewage discharged to a mechanical-biological SBR sewage treatment plant with hydraulic throughput of 600 $m^3 \cdot d^{-1}$.

RESULTS AND ANALYSIS

As the initial elaboration of the research material, a scatter diagram was made showing the values of the share and addition of extraneous waters, as well as concentrations of selected pollutants in raw sewage. On the basis of the course of the scatter diagram regression lines were fitted, describing the dependencies between the share or addition of extraneous waters and the concentration of selected pollutants in raw sewage. A sample scatter diagram with fitted nonlinear regression line was presented in Figure 1.

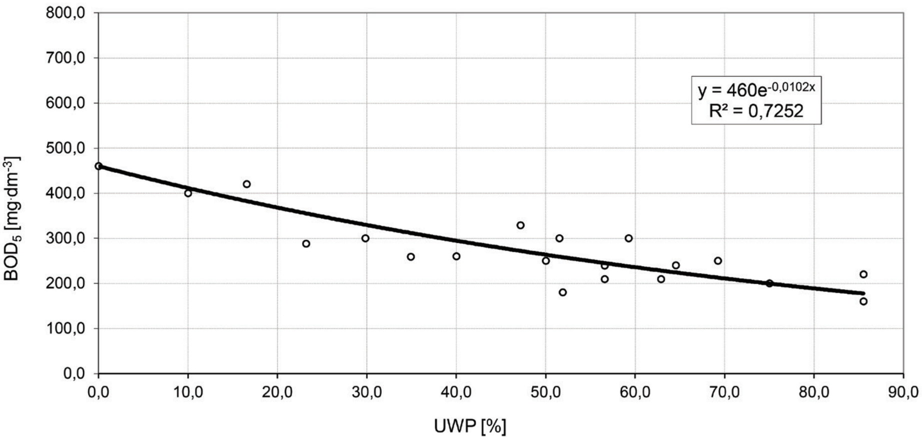

Figure 1. Scatter diagram with regression line showing the dependence between the share of extraneous waters and BOD_5 value in raw sewage in sewer system A.

Basing on the regression equations, values of BOD_5, COD, total nitrogen and phosphorus were computed for individual values of UWP and DWP. Finally, proportions between selected values of pollution indices were calculated for individual values of UWP and DWP. Obtained results were presented in Table 1.

Results of the investigations corroborated the stated research thesis assuming that extraneous water impact proportions of pollutant concentrations in raw sewage (COD:BOD_5, BOD_5:N, BOD_5:P and COD:P).

Table 1. Effect of the share (UWP) or addition of extraneous waters on the analysed proportions of pollution indices values in raw sewage important for sewage treatment using activated sludge method

UWP [%]	DWP [%]	COD : BOD_5 [–]		BOD_5 : N [–]		BOD_5 : P [–]		COD : P [–]	
		Sewer A	Sewer B	Sewer A	Sewer B	Sewer A	Sewer B	Sewer A	Sewer B
0	0	1.63	1.53	4.78	4.30	35.72	32.57	58.22	49.98
5	5	1.66	1.57	4.68	4.21	34.63	31.73	56.78	49.73
10	11	1.68	1.60	4.58	4.12	33.57	30.92	55.38	49.48
15	18	1.71	1.63	4.49	4.04	32.55	30.12	54.01	49.24
20	25	1.74	1.67	4.39	3.95	31.55	29.35	52.68	48.99
25	33	1.77	1.70	4.30	3.87	30.59	28.60	51.38	48.75
30	43	1.80	1.74	4.21	3.79	29.66	27.86	50.11	48.51
35	54	1.83	1.78	4.12	3.71	28.75	27.15	48.87	48.26
40	67	1.86	1.82	4.04	3.63	27.87	26.45	47.66	48.02
45	82	1.89	1.85	3.95	3.56	27.02	25.77	46.49	47.78
50	100	1.92	1.89	3.87	3.48	26.20	25.11	45.34	47.54
55	122	1.95	1.93	3.79	3.41	25.40	24.47	44.22	47.31
60	150	1.99	1.97	3.71	3.34	24.62	23.84	43.13	47.07
65	186	2.02	2.02	3.64	3.27	23.87	23.23	42.06	46.84
70	233	2.05	2.06	3.56	3.20	23.14	22.63	41.02	46.60
75	300	2.09	2.10	3.49	3.14	22.44	22.05	40.01	46.37
80	400	2.12	2.15	3.41	3.07	21.75	21.48	39.02	46.14

The first analysed COD:BOD_5 proportion informs if raw sewage inflowing to the treatment plant is biodegradable, i.e. susceptible to biochemical decomposition. During rainless weather analysed value of proportion, in both sewer systems, was lower than 1.8. For sewer system A the proportion was 1.65, while for sewer system B – 1.53. The numbers result from high, considering household sewage, BOD_5 value, which for sewer A was 533 and for sewer B 460mg$O_2 \cdot dm^{-3}$. During the extraneous waters infiltration to the sewer system, the analysed proportions were changing unfavourably. At 35% share of extraneous waters in sewer A and 50% share in sewer B, the value of COD:BOD_5 proportion exceeded the limit value of 1.80. In case when the share of extraneous waters constituted 80%

of the daily raw sewage discharge to the treatment plant, the value was 2.12 in sewer A and 2.15 in sewer B. Observation of BOD_5 and COD values in raw sewage during increasing inflows of extraneous waters revealed that the waters carry certain amount of pollutants characterised by COD value. These pollutants may be washed off from the ground and enter the sewer system through the openings in sewer catch pit manholes (Kaczor, 2009).

In case of BOD_5:Nproportion, important for the effective denitrification, in both analysed objects a worsening of raw sewage properties in this respect was observed during extraneous waters infiltration. In the denitrification process occurring in the hypoxic chamber of the biological reactor during nitrogen compounds reduction, microorganisms of the activated sludge use 2.86 gBOD_5, for removal of 1 g of nitrate nitrogen (Sadecka, 2010). At BOD_5:N proportion lower than 4 it is necessary to introduce organic compounds to external sewage, i.e. supply the microorganisms with external source of carbon (Dul *et al.*, 2014). Another drawback of such solution is decrease in the sewage alkalinity. In case of the analysed objects, during rainless weather, BOD_5:Nproportion in raw sewage was correct (4.78 in sewer A and 4.30 in sewer B), however with the inflow of extraneous waters during wet weather in both sewer systems it changed unfavourably. Already at 20% share of extraneous waters in sewer system A and 45% share in sewer system B, composition of raw sewage indicated potential problems with the available carbon quantity in denitrification process. At maximum inflows of extraneous waters (*UWP* = 80%), the value of BOD_5:N proportion was 3.41 in sewer system A and 3.07 in sewer B.

Decreasing values of BOD_5:Nproportion with extraneous waters inflow to the sewer may be explained by the fact that these waters carry certain amounts of nitrogen compounds. It is probable regarding the fact that some interceptors of both sewer systems run along green areas or arable fields fertilised with artificial fertilisers.

In biological sewage treatment processes connected with phosphorus removal, BOD_5:P is important. During biological dephosphatation, bacteria accumulating phosphorus decompose organic substances which are their potential source of carbon. At effective dephosphatation, in result of which total phosphorus concentrations in treated sewage does not exceed $1 mg \cdot dm^{-3}$, the BOD_5:P proportion should not be lower than 25. In the analysed sewer systems, during rainless weather, the value of the studied proportion was much higher than 25, but during wet weather it decreased. In sewer A, at 60% share of extraneous waters, and 55% share in sewer B, the BOD_5:Pproportion was lower than 25. In result, at increased inflows of extraneous waters to the sewer system, like in the case of nitrogen compounds reduction, it is necessary to supply external source of carbon for the biological reactor.

The last researched COD:P proportion was maintained even at maximum inflows of extraneous waters to both sewer systems. In raw sewage the proportion should be higher than 36. COD:P correlation, like BOD_5:P proportion informs about a sufficient quantity of carbon containing organic compounds in the processes accompanying biological phosphorus removal. The proper value of the analysed proportion in raw sewage during wet weather may be explained by extraneous waters carrying some amounts of COD containing pollutants washed off the ground.

The conducted research demonstrated unmistakably that extraneous waters periodically flowing into sanitary sewer system carry some amounts of pollutants which change the chemical composition of raw sewage and proportions of individual pollution indices. Determining how much and which pollutants are supplied by extraneous waters is difficult or even impossible due to inevitable process of blending these waters with sewage. Regarding the impact of extraneous waters on sewage treatment plant operation, the conducted research has mainly cognitive value, because according to the regulations currently in force, if rainwater in the amount exceeding 100% of household sewage flows into the treatment plant, the operation of sewage treatment plant should not be assessed. However, it should be remembered that extraneous waters are impounding sewage in interceptors and catch pits, owing to which their impact on sewage composition may persist even for several days following the last rainfall. Then the share of these waters in daily inflows to treatment plant will be lower than 100% and the quality of treated sewage discharged into the receiver may prove unsatisfactory. The conducted investigations confirmed the necessity to maintain the tightness of sewer system and efficient elimination of the sources of accidental waters inflow to sanitary sewer system.

CONCLUSIONS

1. Presented investigations revealed that extraneous waters penetrating the sanitary sewer during the wet (rainy) weather carry certain amounts of pollutants which impact the chemical composition of raw sewage.
2. Extraneous waters inflowing to separate sewer systems, in the first place cause sewage dilution, but simultaneously change proportions of individual pollution indices values.
3. At 50% share of extraneous waters or an addition of 100% of extraneous waters in the sewage inflowing to separate sewers, the proportions of COD:BOD_5, BOD_5:N and BOD_5:P change unfavourably. Failure to maintain the above mentioned proportions in raw sewage may lead to a deficiency of organic compounds during biological processes of biogenic

compounds removal using activated sludge method and therefore can affect the quality of treated sewage discharged into the receiver.

4. Obtained research results are an additional argument for more intensive activities which should be initiated by the sewer network operators to eliminate or limit the causes of extraneous waters inflow to sewer systems.

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