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QUANTITATIVE-QUALITATIVE ANALYSIS OF SEWAGE FOR THE NEWLY DESIGNED SANITARY SEWAGE SYSTEM

ANALIZA ILOŚCIOWO-JAKOŚCIOWA ŚCIEKÓW DLA NOWO PROJEKTOWANEJ KANALIZACJI SANITARNEJ

Abstract: A basic kind of engineering activity improving quality and comfort of citizens' life is maintenance of the suitable sanitary state. The above may result from suitable devices and buildings of sewage transport and treatment. The correctly designed sewer system assures the uninterrupted intake of sewage at the minimization of the negative impact on human health and the environment. The existing sewer systems are frequently extended for new lines causing the growth of the quantity and load of pollutions in sewage entering the *wastewater treatment plant* (WWTP). This paper shows the results of the quantitative-qualitative analysis of sanitary sewage from the newly designed sanitary sewage system in the west site of Rejowiec Fabryczny. Our analysis was conducted to determine the increase of the pollutants load entering the WWTP. The analysis was based on the pollutants load in average-twenty-four hours samples of raw sewage sampled in the screens chamber in mechanical-biological WWTP. The results of sewage qualitative analyses from the period of years 2008–2009 were adopted to our research. The pollutants loads in the newly designed network in the west of Rejowiec Fabrycznego were defined basing on the research of the inequality of the water demand in seven household. This analysis allowed the pollutants loads prediction in raw sewage inside the newly designed network of the sanitary sewage system. The proposed analysis demands validation permitting for confirmation of assumed simplifications.

Keywords: sanitary sewage, sewage quality, sanitary sewage system, sewage quantity

The quantity and quality of sewage originated from households mainly depends on personal habits and standard of households accessory. It is assessed that the largest loads of pollution are generated in the toilet bowls and the least – in the handbasins [1]. The load of pollution in sewage is often determined by its origin. The municipal, industry or agricultural wastewaters often need individual approach in the decontamina-

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tion process in regard of their specific composition [2]. The composition and the quantity of sewage entering the *wastewater treatment plant* (WWTP) are often modified by infiltration and coincidental water (rainwater, meltwater, groundwater) getting to the sewage system [3]. Moreover, physical and biochemical processes occurring in the system affect the quality of sewage entering the WWTP. The developing biomass of heterotrofic microorganisms causes the process of sewage self-purification, or loss of the pollution load in the WWTP inflow against the load getting to the system [4–6]. Thus, designing of a WWTP should be more often integrated with designing of a sewage system. These objects should be treated as a whole instead of individual objects, because the sewage decontamination process occurs as early as the stage of sewage transport in the system [7–11].

The quantitative-qualitative characteristic of sewage is a necessary element both at the stage of designing of new WWTP and during extending or modernization existing objects [12].

The aim of this work was to conduct the quantitative-qualitative analysis of the sewage flowing in the WWTP from five newly designed parts of the sanitary sewage system in Rejowiec Fabryczny, Poland and to show the quantitative-qualitative distribution of this sewage in the successive hours during a natural day.

Material and methods

Characteristics of research object

A newly designed sanitary sewage system in the west part of Rejowiec Fabryczny city was used as a research object, on the basis which the quantitative-qualitative analysis of the sewage was conducted. The system includes the regions of Chelmska, Dworcowa, Lubelska and Boczna streets and it contains 90 individual households.

The Rejowiec Fabryczny city is located in the south-east of Lublin province. Its area amounts about 14 square kilometers [13]. Nearly 5 thousand citizens live there and population density amounts 342 persons per square kilometer [14]. The length of the combined sewer in-service is equal to 9.3 kilometers and the length of connections – 2.0 kilometers, that denotes 85 % households conected the sewage system. Sewage from both, existing and newly designed sewers will flow into the mechanical and biological WWTP with efficiency 800 cubic meters per a natural day. The WWTP has been existing since 1991 and it was modernised in 2003 [13, 15].

The newly designed sanitary sewage system, used in the our studies, consists of 5 parts including main sewers and connections. Each part will be connected with the existing system. The designed sewer is going to be made of PVC SN 4 pipes, overall length 4085 m. There will be chambers made of PE (425 mm in diameter) and concrete chambers (1200 mm in diameter) as an accessory of the system. Details on quantitative and size parameters are presented in Table 1 [13].

Table 1

The characteristics of the newly designed sanitary sewage system in Rejowiec Fabryczny

No. of sewer part	System length L [m] / Number of segments [unit]			Number of chambers [unit]		Number of segments / chambers [unit]
	PVC 160 [mm]	PVC 200 [mm]	PVC 315 [mm]	PE 425 [mm]	Concrete 1200 [mm]	
1	71 / 7	588 / 21	985 / 23	22	30	51 / 52
2	37 / 3	69 / 3	—	5	2	6 / 7
3	154 / 10	825 / 28	257 / 12	32	19	50 /51
4	62 / 5	222 / 9	—	11	4	14 / 15
5	104 / 6	711 / 26	—	20	13	32 / 33

The route of newly designed gravity sanitary sewage system was determined by ground slopes and existing subterranean and aerial infrastructure [16]. Pipes will be assembled below ground freezing depth, which is equal to 1.0 m for the second climate zone [17]. The scheme displaying the structure of the system (part no. 4) is presented in Fig. 1.

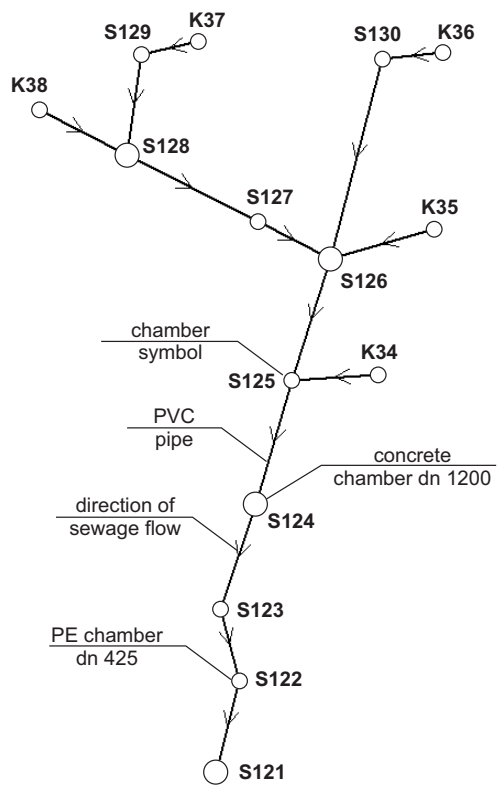

Fig. 1. Scheme displaying the structure of system (part no. 4)

Investigation method

The quantity of sewage flowing in the newly designed system was determined on the basis of average standards of water intake and number of citizens living in the area served by the new sewer.

It was assumed that 4 residents live in each household and the building is connected to a water supply system and there are toilet and bathroom and local source of hot water in the building.

On the basis of these assumptions the value of 100 $dm^3 \cdot person^{-1} \cdot d^{-1}$ was accepted as a the water intake standard [18]. Average quantity of sewage was calculated as:

$$Q_d^{śr} = q_j \cdot LM \tag{1}$$

where: q_j – unit daily quantity of sewage as a result of quantity of water consuming by one citizen [$dm^3 \cdot person^{-1} \cdot d^{-1}$], q_j = 80–100 $dm^3 \cdot person^{-1} \cdot d^{-1}$,
LM – number of citizens living in the area served by the new sewer [person].

Hourly and daily irregularity coefficients were assumed as N_h = 2.0 and N_d = 3.0, respectively, because the number of citizens is less than 5000 persons [19]. Maximal daily and hourly quantities of sewage were calculated taking into account daily and hourly irregularity of water intake:

$$Q_d^{\max} = Q_d^{śr} \cdot N_d \tag{2}$$

$$Q_h^{\max} = \frac{Q_d^{\max}}{24} \cdot N_h \tag{3}$$

where: N_d – daily irregularity coefficient of water intake [-],
N_h – hourly irregularity coefficient of water intake [-].

To provide for infiltration and case water maximal hourly quantity of the sewage from households was enlarged 25 %. On the basis of sewage quantity for particular segments of the system it was calculated the overall quantity of sewage flowing in the WWTP from the newly designed system as 11.25 $m^3 \cdot h^{-1}$. Details of calculations are presented in Table 2.

Analysis of sewage quality was conducted on the basis of results of investigation of raw sewage flowing in the WWTP accessible by courtesy of Zaklad Wodociagow i Kanalizacji in Rejowiec Fabryczny, conducted by Laboratorium Zakladu Inzynierii Srodowiskowej Eko-Projekt Sp. z o. o. Accessible results include analyses of sewage quality conducted in consecutive quarter of years 2008 and 2009. As parameters as BOD (*Biochemical Oxygen Demand*), COD (*Chemical Oxygen Demand*) and TSS (*Total Suspended Solids*) in average-day swage samples were tested. Results of analysis of sewage quality are presented in Table 3 (analysis according to [20–22]). Average

pollutant load in raw sewage flowing in the WWTP was determined discounting the first measurement.

Table 2

The compilation of the sewage quantity from particular parts of the newly designed sewage system

No. of part	Citizens number, *LM* [person]	Sewage quantity				
		Unit daily, q_j [$dm^3 \cdot person^{-1} \cdot d^{-1}$]	Average daily, $Q_d^{avg.}$ [$dm^3 \cdot d^{-1}$]	Maximal daily, Q_d^{max} [$dm^3 \cdot d^{-1}$]	Maximal hourly, Q_h^{max} [$dm^3 \cdot h^{-1}$]	Maximal hourly, Q_h^{max} [$dm^3 \cdot h^{-1}$]
1	112	100	11200	22400	3500	3.50
2	16	100	1600	3200	500	0.50
3	120	100	12000	24000	3750	3.75
4	36	100	3600	7200	1125	1.13
5	76	100	7600	15200	2375	2.38
					Sum	11.25

Table 3

The quality of sewage flowing in the WWTP in years 2008 and 2009

No.	Quarter	Day	Sewage quality		
			BOD	COD	TSS
			[$mg \cdot dm^{-3}$]		
1	I	14.03.2008	95.7	200	40
2	II	19.06.2008	781	1660	1100
3	III	12.09.2008	388	1107	258
4	IV	12.12.2008	579	2283	994
5	I	01.04.2009	534	1503	560
6	II	16.06.2009	320	985	594
7	III	12.09.2009	511	1500	1070
8	IV	11.12.2009	345	1193	544
Average load determined discounting result of measurement in 1st quarter of year 2008			494	1462	731

To provide for irregularity of quantity and quality of sewage flowing in the WWTP, the sewage inflow pattern determined on the basis of water intake in seven selected households in consecutive hours during a day was used [15]. Measurement of quantity of water intake was made using household water-meter. Investigation was conducted in 2009. Obtained results of sewage inflow irregularity are presented in Table 4.

Quantitative irregularity of sewage inflow was determined multiplying maximal hourly quantity of sewage (11.25 $m^3 \cdot h^{-1}$) by coefficient of inflow irregularity in consecutive hours of a day.

Table 4

Coefficients of irregularity of inflow of sewage to WWTP

Hour	Coefficient of sewage inflow irregularity [-]	Hour	Coefficient of sewage inflow irregularity [-]
1:00–2:00	0.02	13:00–14:00	0.25
2:00–3:00	0.00	14:00–15:00	0.38
3:00–4:00	0.00	15:00–16:00	0.61
4:00–5:00	0.00	16:00–17:00	0.34
5:00–6:00	0.00	17:00–18:00	0.22
6:00–7:00	0.38	18:00–19:00	0.15
7:00–8:00	0.45	19:00–20:00	0.37
8:00–9:00	0.35	20:00–21:00	1.00
9:00–10:00	0.42	21:00–22:00	0.67
10:00–11:00	0.33	22:00–23:00	0.59
11:00–12:00	0.33	23:00–24:00	0.51
12:00–13:00	0.23	24:00–1:00	0.06

Qualitative irregularity of sewage inflow was calculated multiplying average pollutant load determined on the basis of calculation presented in Table 3 by maximal hourly quantity of sewage, analogously to the method described by J. Adamek i K. Kudlik [23], taking into account coefficients of inflow irregularity (Table 4). Analysis was conducted treating all segments of newly designed sewer as one system, for which sewage quantity and pollutant load in consecutive hours of a day were determined.

Obtained results analysis

Calculations conducted for newly designed gravitational sanitary sewage system in the west part of Rejowiec Fabryczny enable maximal hourly quantity of sewage, average pollutant load and both quantitative and qualitative irregularity of inflowing sewage to be determined. It was established that maximal quantity of sewage flowing in the WWTP during an hour will be equal to 11.25 m^3 and average pollutant loads for this sewage will be as follow: BOD = 494 mg · dm^3, COD = 1462 mg · dm^3, TSS = 731 mg · dm^3. Distribution of quantitative inflow irregularity is presented in Fig. 2. Maximal quantity of sewage was observed at 8.00 p.m. Simultaneously, three other crests – at 7.00 a.m., 9.00 a.m. and 3.00 p.m. – were observed. The sewage flow for the mentioned hours amounted 5.06 $m^3 \cdot h^{-1}$, 4.73 $m^3 \cdot h^{-1}$ and 6.86 $m^3 \cdot h^{-1}$, respectively. Lack of WWTP inflow was observed at night between 2.00 a.m. and 5.00 a.m.

Distribution of pollutants load flowing in the WWTP in consecutive hours is presented in Fig. 3. Because qualitative pattern analogous to inflow pattern was used, the largest pollutant loads were obtained for an hour 8.00 p.m. Values of the pollutants were following then: BOD = 5.56 $kgO_2 \cdot h^{-1}$, COD = 16.44 $kgO_2 \cdot h^{-1}$, TSS = 8.23 $kgO_2 \cdot h^{-1}$. For the first crest for an hour 7.00 a.m. there was observed BOD = 2.50 $kgO_2 \cdot h^{-1}$, COD = 7.40 $kgO_2 \cdot h^{-1}$, TSS = 3.70 $kgO_2 \cdot h^{-1}$. For an hour 9.00 a.m. less values of pollutants concentrations were noticed: BOD = 2.33 $kgO_2 \cdot h^{-1}$, COD = 6.91

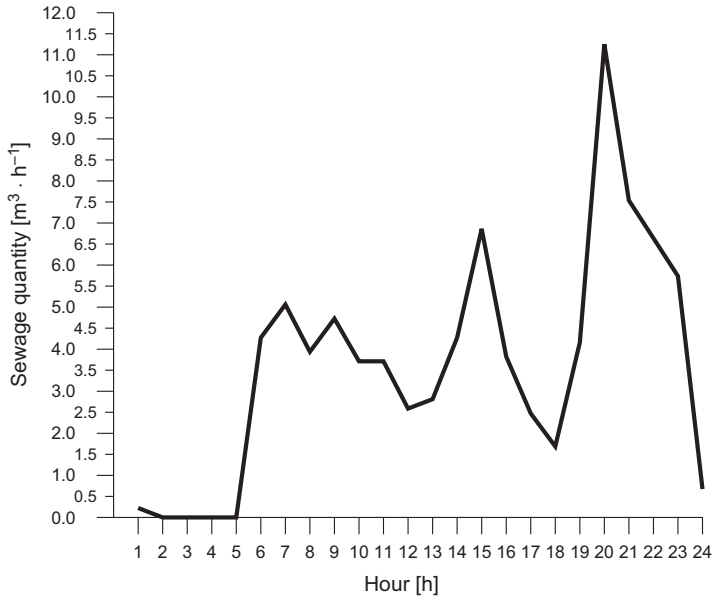

Fig. 2. The sewage quantity from the newly designed system running up to flowing in the WWTP

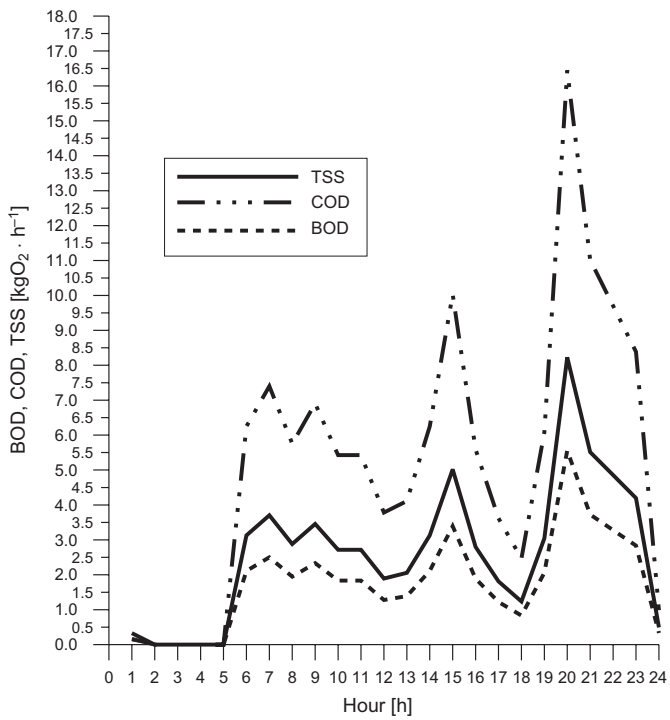

Fig. 3. Pollution load flowing in WWTP from newly designed sewage system

$kgO_2 \cdot h^{-1}$, TSS = 3.46 $kgO_2 \cdot h^{-1}$. In turn, larger values were observed for an hour 3.00 p.m.: BOD = 3.39 $kgO_2 \cdot h^{-1}$, COD = 10.03 $kgO_2 \cdot h^{-1}$, TSS = 5.02 $kgO_2 \cdot h^{-1}$. Analogously to qualititative distribution, there is not any changes in pollutant load between 2.00 a.m. and 5.00, because sewage does not flow in the WWTP in this time.

Conclusions

Results of conducted qualititative-quantitative analysis of sewage flowing in the WWTP from newly designed sanitary sewage system forecast both sewage quantity and pollutant load in row sewage flowing in the WWTP. They give a notion of a distribution of sewage quantity and pollutants concentration in consecutive hours of a natural day. They point out hours connected with quantitative-qualitative culmination of sewage in Rejowiec Fabryczny and display the time of lack of sewage flow in the WWTP. Thus, obtained results of the analysis enable operating, repairs, modernizations or possibly changes of sewage treatment technology to be better planned. Conducted analysis also improves that larger sewage flow after extending of the system in the city will not cause passing of maximal efficiency of the WWTP.

Simultaneously, the conducted analysis involves some errors, that can be caused by used simplifications and assumptions. Thus, its verification in real conditions is necessary to support accurateness of used patterns and assumed simplifications. Moreover, it is necessary to investigate that the pattern displaying irregulation of inflowing sewage quantity can be used to display irregulation of pollutants concentration in sewage.

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ANALIZA ILOŚCIOWO-JAKOŚCIOWA ŚCIEKÓW DLA NOWO PROJEKTOWANEJ KANALIZACJI SANITARNEJ W ZACHODNIEJ CZĘŚCI MIASTA RAJOWIEC FABRYCZNY

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Abstrakt: Podstawowym rodzajem aktywności inżynierskiej pozwalającym na poprawę jakości i komfortu życia mieszkańców jest utrzymanie odpowiedniego stanu sanitarnego. Możliwe jest to dzięki urządzeniom i budowlom pozwalającym na odprowadzanie i unieszkodliwianie ścieków. Prawidłowo zaprojektowana sieć kanalizacyjna zapewnia nieprzerwany odbiór ścieków przy minimalizacji negatywnego wpływu na zdrowie i środowisko naturalne. Coraz częściej istniejące już sieci kanalizacyjne są rozbudowywane, co powoduje wzrost ilości i ładunku zanieczyszczeń w ściekach dopływających do oczyszczalni. Niniejsza praca przedstawia wyniki analizy ilościowo-jakościowej ścieków sanitarnych z nowo projektowanej kanalizacji sanitarnej w zachodniej części miejscowości Rejowiec Fabryczny. Analiza miała na celu określenie wzrostu ładunku zanieczyszczeń dopływających do oczyszczalni. Przeprowadzono ją na podstawie analizy ładunku zanieczyszczeń w próbkach średnio-dobowych ścieków surowych, dopływających do kraty w istniejącej mechaniczno-biologicznej oczyszczalni ścieków. Do analizy przyjęto badania jakości ścieków z okresu 2008–2009, przeprowadzanych w kolejnych kwartałach. Ładunek zanieczyszczeń w kolejnych godzinach w ciągu doby z nowo projektowanej sieci w zachodniej części Rejowca Fabrycznego określono na podstawie badań nierównomierności rozbioru wody w siedmiu gospodarstwach domowych. Przeprowadzona analiza pozwala na określenie całkowitego prognozowanego ładunku zanieczyszczeń w ściekach surowych, doprowadzanego przez nowo projektowaną sieć kanalizacji sanitarnej. Jednocześnie określa ona ładunki dopływające w poszczególnych godzinach w ciągu doby. Zaproponowana analiza wymaga przeprowadzenia weryfikacji w celu potwierdzenia bądź odrzucenia prawidłowości zastosowanych uproszczeń.

Słowa kluczowe: ścieki sanitarne, jakość ścieków, kanalizacja sanitarna, ilość ścieków