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Water quality comparison for various drainage systems for 2000 equivalent population

P Hlustik¹ and J Raclavsky¹

¹Institute of Municipal Water Management, Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95, Brno, 602 00, Czech Republic

Abstract. The article deals with the comparison of wastewater quality in gravity and alternative drainage systems. The gravity drainage systems include combined and sanitary sewerage systems, the alternative systems encompass pressure and vacuum sewerage systems. The difference in the quality of wastewater conveyed to a wastewater treatment plant is influenced by the relevant sewerage system, its technical condition and regular maintenance. The objective of the article is to highlight the differences in wastewater quality with respect to BOD, COD, SS, NH₄, Nt and Pct indicators based on the chemical analyzes conducted over several years of operation. The comparison is made for selected municipalities in the Czech Republic in 2005-2019 for various sewerage systems.

1. Introduction

Drainage systems in municipalities up to 2000 equivalent inhabitants and the correct choice of sewerage type are always very important. We consider as the conventional drainage systems in the area of interest in the Czech Republic a combined or separate sewerage system based on gravity, non-pressure principles of wastewater transport.

Alternative sewerage systems include pressure and vacuum sewerage systems. Wastewater monitoring at the outlets of various types of sewerage has shown that the effect of wastewater transport on its quality is apparent. The choice of the type of sewerage has a direct impact on the choice of technology and the design of wastewater treatment plant parameters. The wastewater treatment plant design must take into account various hydraulic and material loads in relation to the relevant type of sewerage.

2. Drainage systems

To select an investment variant, it is important to have information related to the sewerage operation which is often crucial for selecting one of the compared variants. Economic analyses of capex and opex [1] are important when selecting from amongst the proposed sewerage options. Information on the system reliability resulting from the number and type of equipment installed along the sewerage system should be taken into account.

2.1. Gravity drainage systems

Combined and separate drainage systems with gravity wastewater transport are considered as conventional methods of wastewater transport for continuous drainage in the relevant areas. The conventional drainage method emphasises simplicity and reliability of operation. In conventional sewer systems, lift stations, booster pump stations and pressurized sections are only used only when necessary, and in short sections [2].



2.2. *Alternative drainage systems*

The pressurized and vacuum systems are used as an alternative to drain wastewater from buildings instead of conventional gravity sewers. They are used in cases where gravity sewerage would have to be laid very deeply at a disproportionate cost due to insufficient terrain inclination [2]. Vacuum and pressurized sewer system are intended solely for sanitary sewage and they can not drain rainwater. In both cases, these are branching pipe systems (pressurized sewerage can be looped) supplemented with a system of collecting shafts [3]. The gravity house drains from buildings are connected to the shafts. In flat areas with high groundwater levels, these are ideal drainage systems with a significantly lower volume of earthworks (compared to conventional gravity-flow sewerage).

2.2.1. Pressurized sewerage. The pressurized systems are used as an alternative to drain wastewater from buildings instead of conventional gravity sewers. They are used in cases where gravity sewerage would have to be laid very deeply at a disproportionate cost due to insufficient terrain inclination.

2.2.2. Vacuum sewerage. This sewerage is used mainly in areas where there are increased requirements for the protection of groundwater and also in flat land where pressurized or gravity sewerage systems would have to be constructed instead with a large number of lift stations

3. **Advantages and disadvantages of the individual drainage systems**

The following chapters compare the advantages and disadvantages of operating a gravity-flow combined, separate sanitary sewerage, separate pressurized sewerage and vacuum sewerage systems.

3.1. *Gravity sewerage*

The advantages of combined sewer systems include lower capex compared to the separate system; probably a simpler solution to the of ownership rights to be settled during the engineering work needed for the land-use permit documentation; in most cases, lower demands on connecting adjacent properties to a combined sewer system. Summary of advantages:

- trouble-free and almost maintenance-free operation,
- minimum costs of operating the sewer system (only in relation to equipment - repair and maintenance costs; sediment checks and cleaning in case of small gradients) [4],
- near-zero energy consumption of the sewer system (operation of the sewerage is not dependent on electricity, except for where there is equipment in the system) [4],
- Possibility of draining sanitary sewage as well as rainwater,
- utilization of morphological profile: independent gravity wastewater drainage,
- simple connection of gravity connections to the main gravity sewer,
- Easy application of CCTV systems to monitor the sewerage.

The disadvantages of the combined system include higher environmental impacts on the receiving body of water. As regards combined systems, it is necessary to consider the financial demands on progressive rehabilitation of the sewer system. Summary of disadvantages:

- higher capex (earthworks: deeper depths and pipe profiles),
- regular inspection of sediments in the sewer system and cleaning, if necessary,
- laying foundations under adverse hydrogeological conditions worsens the sewer foundation works [5, 6],
- larger number of sewerage facilities on the network as require by the applicable ČSN.

3.2. *Pressurized sewerage*

The pressurized systems are used as an alternative to drain wastewater from buildings instead of conventional gravity sewers. They are used in cases where gravity sewerage would have to be laid very deeply at a disproportionate cost due to insufficient terrain inclination. Pressurized sewer system is intended solely for sanitary sewage and they cannot drain rainwater. Summary of advantages:

- lower capex (earthworks: earthworks: more shallow depths of laying and pipe profiles),
- more flexible pressurized sewerage designing in combination with gravity sewerage [4],

- possibility of overcoming larger reverse sloping in the territory,
- leaks can be easily detected on the pressure pipeline,
- absence of rainwater and groundwater (drainage) water in this type of sewerage
- use of these sewerage systems in scattered housing development with several separate catchment areas, and use in areas with unfavorable conditions for sewer foundations.

Summary of disadvantages:

- high energy intensity of the system due to number of pumping stations,
- when connecting more buildings and inhabitants one PS one MS, there is often arguments due to higher payments for electricity and breakdowns (in case of improper use),
- the connected users usually pay for the energy consumed by the pump in addition to the sewage tariffs,
- poor accessibility of the manholes if located on private land,
- sediments settling in pipes due to minimum flow rates at night [7],
- longer retention times in the pipeline results in the formation of anaerobic [7],
- wastewater, which is transported under anaerobic conditions, emits intensive odours [7],
- increased and long-term inflow of anaerobic water affects the technology of WWTPs,
- if sedimentation is long-term, the pipeline must be flushed with compressed air and water.

3.3. Vacuum sewerage

This sewerage is used mainly in areas where there are increased requirements for the protection of groundwater and also in flat land where pressurized or gravity sewerage systems would have to be constructed instead with a large number of lift stations. Summary of advantages:

- lower capex for the construction of sewerage systems,
- vacuum valves in the collecting shafts do not require el. power to operate, the valve profile is fully flow-through - thanks to the design it can also suck hard and elastic objects
- wastewater aeration during transport, there is no risk of anaerobic conditions [4],
- longer lifetime of the vacuum valves compared to domestic pressurized sewer pumps
- leaks can be easily detected on the vacuum pipeline,
- absence of rainwater and groundwater (drainage) water in this type of sewerage
- higher vacuum valve capacity compared to domestic pressurized sewer pumps
- high sewage flow rate eliminates sedimentation or clogging (up to 6 m/s)
- after opening the suction valve, wastewater and air are sucked into the pipe system.

Summary of disadvantages [8]:

- necessary installation of vacuum stations,
- the design of vacuum pipelines is a size larger than the pressurized pipeline,
- if the valve is not closed, the energy demand of the whole system increases significantly,
- absence of long-term experience with the operation of this system in the Czech Republic,
- system operational demands, shorter service life and higher breakdown rate.

4. Quality and quantity of wastewater

Statistical data processing was carried out using ten thousand values of wastewater concentration indicators at the inflow to 40 WWTPs over different years [9], operated by water companies. In order to optimize the design parameters of wastewater treatment plants, the WWTPs in the given category were always selected as mechanical-biological wastewater treatment plants with a low-load activation system. All selected wastewater treatment plants have technologies guaranteeing the efficacy of wastewater treatment and meet the emission indicators. The resulting water quality indicators for gravity combined sewerage, gravity separate sewerage, pressurized separate systems and vacuum systems are shown in Table 1.

The proposed technologies of wastewater treatment in individual municipalities have not been compared. The comparative and common indicator of water quality is the compliance with water quality emission standards set in decision of the water authority for the relevant WWTP [10]. The

efficiency of all assessed WWTPs was satisfactory, the efficiency in relation to all water quality indicators did not exceed the maximum concentrations and complied with the permissible wastewater concentrations specified in the water management documents [9].

4.1. Wastewater quality

Another frequent assessment made by the operators is the determination of percentiles c95 and c90. This is due to the conversion of emission standards to annual mean values (proportion of the permissible concentration o 95% and average concentration) and the determination of pollution standards for the indicators of permissible surface water pollution using the c90 value.

Table 1. Water quality comparison for various drainage systems.

Drainage systems	BOD [mg.l⁻¹]	COD [mg.l⁻¹]	SS [mg.l⁻¹]	N_t [mg.l⁻¹]	NH₄ [mg.l⁻¹]	P_t [mg.l⁻¹]	pH [-]
Average							
Combined sewerage	206.8	508.3	281.6	60.2	39.2	7.3	7.7
Sanitary sewerage	465.7	963.6	427.7	118.0	94.6	13.4	7.9
Pressurized sewerage	797.6	1649.5	871.6	180.6	140.5	18.5	8.2
Vacuum sewerage	666.7	1402.1	780.2	145.5	108.1	16.6	8.0
Average concentration	350.0	750.0	400.0	60.0	35.0	20.0	7.0
Median							
Combined sewerage	199.6	471.4	232.6	65.4	38.5	7.1	7.7
Sanitary sewerage	524.5	1031.5	446.3	112.1	93.5	13.0	7.8
Pressurized sewerage	787.5	1592.1	863.5	188.7	133.7	18.5	8.2
Vacuum sewerage	659.2	1398.4	829.1	141.9	103.0	16.4	8.0
Percentile C ₉₀							
Combined sewerage	337.6	843.2	468.0	82.4	68.3	9.6	7.8
Sanitary sewerage	604.4	1191.5	568.4	159.5	125.0	18.6	8.3
Pressurized sewerage	905.4	1855.5	960.5	234.2	198.1	20.8	8.3
Vacuum sewerage	769.9	1541.2	870.3	174.8	127.8	18.6	8.2
Percentile C ₉₅							
Combined sewerage	338.7	863.5	528.1	84.0	68.9	9.8	7.9
Sanitary sewerage	604.7	1236.3	579.0	173.9	137.7	19.1	8.5
Pressurized sewerage	930.9	1959.5	1036.3	249.6	202.7	21.6	8.3
Vacuum sewerage	780.1	1590.2	881.9	175.1	129.9	18.9	8.3

The overall comparison of wastewater quality in the individual indicators of combined gravity, sanitary gravity, pressurized and vacuum sewerage systems shows that the highest concentrations of organic load are related to the alternative sewerage systems, i.e. pressurized and vacuum sewerage systems. Wastewater from pressurized and vacuum sewerage systems has high pollution concentrations due to long retention time during transport to the WWTP. Unlike combined and separate sewerage, this is an oxygen-free environment in which anoxic and anaerobic processes take place. Biological processes are significantly influenced by the total length of the sewerage system, the number of pumping stations and by-pass shafts. The volume of ballast water found in the pressurized and vacuum sewers is minimal [11].

On the contrary, gravity sewerage systems often experience oxidation of sanitary sewage (this is also often influenced by a significant slope in the longitudinal sewerage profile), which affects the BOD and COD indicators - BOD and COD get degraded by oxic processes [12]. The BOD:COD ratio is approximately 0.5 at the outlet of the gravity, pressurized and vacuum sewerage systems. This value is favourable for the biological wastewater treatability.

4.2. Wastewater quality

Alternative drainage systems are characterized by minimum of infiltration and undesirable inflows into the closed pipe system. Flow characteristics analyses show that the average wastewater production from alternative systems in the monitored areas is 85 l person/day in pressurized sewerage and 87.6 l person/day in vacuum sewerage systems.

The gravity separate sewerage system shows variable daily production of discharged wastewater, mainly depending on the infiltration of ballast water. This frequent infiltration of large volumes of ballast water can significantly affect the efficiency of wastewater treatment at the WWTP. The average value of water production in gravity systems without ballast water is 93.8 l person/day.

The quality of wastewater is often influenced by the structural-technical condition of the sewerage system, which is mainly affected by:

- adherence to standard technical regulations related to the construction
- volume of ballast water
- inadequate gradients in the sewerage which cause sludge sedimentation in the sewerage,
- regular inspection and maintenance of the sewerage.

The main operational indicators affecting the quality of wastewater must be regularly checked by the sewerage system operator.

These indicators include:

- regular flushing of the sewerage system,
- regular inspection of the structural and technical condition - using camera inspections,
- adjustment of the pumping station operation - setting of the switching level by means of floats to pump wastewater due to long retention time in the pumping stations
- quality control of wastewater from discharge pipelines [13],

As an indication, it is appropriate to consider installation of an alternative system where there are multiple reasons for its application. It is important to realize that the operation of these systems differs from the operation of conventional gravity sewer systems, and therefore the operation must be adequately safeguarded. Combinations of alternative and traditional systems can be problematic. In such cases, it is better to convey wastewater through the pressure system to the WWTP separately and, if economically viable, do not discharge the wastewater into conventional sewers.

5. Conclusion

The existing standards and the existing approach to wastewater designs do not take into account the wastewater transport method and the calculations are based on the same design values related to polluted wastewater production. These values were determined at a time of different economic, social and technical conditions and their use is a matter of a conservative and deep-rooted approach of the design engineers.

The aim of this article is to highlight the differences in the design parameters of wastewater production and wastewater quality in relation to various sewerage systems. In practice, it is important to enforce a new approach to designing wastewater treatment plants in the category up to 2,000 PE. The introduction of new design parameters will be related to the company management willingness to adapt to new directions in the field of "Sewerage and wastewater treatment". Experienced design engineers are aware of the difference in wastewater quality for various sewer systems and they usually try to adapt the design parameters for the WWTP calculation. The specific pollution production parameters for these sewage systems cannot be interpreted as surprising, the wastewater quality in these systems shows worse parameters in relation to all indicators.

Discussions concerning the design of sewerage systems and wastewater treatment plants is a solution to recodifying relevant legislative documents, i.e. ČSN 75 6401 [14] and ČSN 75 6402 [15] and to comment on these documents within expert groups (The Czech Water Association).

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