The proposal of recommendations for the operation of vacuum sewerage

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Abstract. This article deals with a comparison of vacuum sewerage system and gravity based sewerage system. It also includes the results of the comparison of both of these systems from various cities, and there are measures suggested on the basis of the findings focused on increasing the efficiency and reducing the operational costs of the selected vacuum sewerage system.

1. Introduction
Waste water discharge and its subsequent treatment has become an integral part of the technical society. However, gravity sewerage is still the most widespread waste water discharge system. This system has many technical, environmental and economic disadvantages [1,2,3]. Nevertheless, there are alternative systems, including vacuum sewerage system, which have recently been used more and more frequently. There are studies trying to compare the vacuum sewerage system with the most common conventional sewerage systems, namely gravity and pressure ones [4]. Another work tries to analyze vacuum sewers from the economic, technical, social, and environmental point of view and to suggest their best use in the areas with decentralized waste water discharge [5,6].

2. Description of vacuum sewerage system and its function
Nowadays, vacuum sewerage system is a commonly used representative of separate sewerage systems with an alternative way of waste water transportation through a pipeline. A diagram of the vacuum sewerage system is shown in figure 1.

Unlike the commonly used gravity sewerage system, waste water transported through a vacuum sewerage system takes advantage of the pressure difference between the atmospheric pressure and the mechanically maintained vacuum in the sewerage pipeline. Waste water from the individual buildings and properties is drained by means of a standard gravity sewerage connection into a collecting shaft, where it is accumulated in a collection sump. The collection sump is installed in the collecting shaft together with a suction valve, which forms the boundary-line between the atmospheric pressure and the vacuum in the sewerage pipeline. The vacuum in the sewerage system is maintained by means of vacuum pumps or ejector pumps located in a central vacuum station. Brief characteristics of the compared municipalities:
2.1. Zvoľe municipality – vacuum sewerage system
Zvoľe municipality is located in the southern part of Šumperk district, between the cities of Zábřeh and Mohelnice. The cadastral area of the municipality has an area of 658 ha and there are 863 permanent residents registered in the municipality. The construction of a vacuum sewerage system ended in 2003. The total length of the vacuum sewerage system is 6.6 km. It consists of two main sewers A and B to which secondary sewers with the pipe profiles of DN 90, DN 110 and DN 160 are connected, and they are discharge into the local waste water treatment plant.

2.2. Loštice municipality – conventional gravity sewerage system
The municipality of Loštice is situated in the southern part of Šumperk district, the administrative area of the town has an area of 1200 ha. Loštice has 3026 permanent registered residents. The sewerage system was built in the second half of the last century, the WWTP was finished in 1999 and the separate sections were interconnected. Today, the uniform gravity sewerage system has the total length of 15.28 km and its arrangement is divided into the left-bank and right-bank parts. Concrete and reinforced concrete pipes with the most commonly used profile of DN 300 to DN 600 are used in most places.

3. Comparison of vacuum sewerage system with gravity one in terms of their preventive maintenance, failure rate, and direct costs

3.1. Preventive maintenance
A long-term and trouble-free operation of the sewerage system requires a suitable design and its execution, but also properly performed preventive maintenance and repairs of the property. These periodically repeated activities are crucial for the sustainability and adequate service life of the sewerage system. Preventive maintenance of a vacuum sewerage system can be divided into three areas: the maintenance of the vacuum station, the outdoor vacuum pipeline and the collection sumps.

The maintenance and control of the vacuum station, especially the vacuum source and pump technology, is the most time-consuming. This activity must be carried out in regular weekly cycles where, along with a routine inspection and maintenance, other operations with a longer, usually monthly, semi-annual and annual period are performed. The maintenance of vacuum sewerage sewers is limited to a visual inspection of the status of the sewerage pipeline protection zone, which is carried out once a year, and a semi-annual check of the functionality of the sectional vacuum pipeline shut-off valves. The preventive maintenance of collecting shafts and suction valves is not planned by the operator, but it is systematically carried out in such a way to check and clean all the collecting shafts, to check the function and status of the suction valves, and to set the control centre every year.
Preventive maintenance on the gravity sewerage system in Loštice is divided into the maintenance of the pumping stations, balancing structures, mountain gullies, sediment control and sewerage sewers cleaning, and the execution of a routine protective deratization. The inspection and maintenance of the potentially problematic objects, i.e. pumping stations and balancing chambers, is performed by the operator according to a maintenance schedule once a week. The mountain gully is checked and maintained quarterly and a routine protective deratization is performed twice a year. A revision of the relevant sections of the sewage system and a camera inspection of the pipeline conditions are carried out according to a plan as well.

3.2. Failure rate
The failure rate is an important part of sewerage system operation with a significant impact on its functionality. Emergency situations represent exactly the kind of the problem when failures in the provision of the waste water discharging service may occur. That is why the main task of the responsible operator is to solve the failure and emergency situations in the shortest possible time and to minimize the impact on the producers. You can see a list of the emergency situations of vacuum and gravity sewerage systems in table 1.

| Table 1. Overview of emergency situations of vacuum and gravity sewerage systems. |
|-----------------------------------------------|-----|----|----|
| Failure type                     | Unit | year 2015 | year 2016 |
|-----------------------------------------------|-----|----|----|
| Vacuum sewerage system            |     |    |    |
| Clogged pump                      | vehicle operation | Km | 1 456 | 1 140 |
|                                  | labour consumption | H  | 42   | 30   |
| Open suction valve                | vehicle operation | Km | 2 444 | 1 928 |
|                                  | labour consumption | H  | 108  | 92   |
| Total                            | vehicle operation | Km | 3 900 | 3 068 |
|                                  | labour consumption | H  | 150  | 122  |
| Gravity sewerage system          |     |    |    |
| Sewer shaft failure              | vehicle operation | Km | 67   | 25   |
|                                  | labour consumption | H  | 36   | 4    |
| Sewerage system clogging        | vehicle operation | Km | 360  | 396  |
|                                  | machine performance | Eh.| 10   | 9    |
| Pump failure                     | vehicle operation | Km | 0    | 15   |
|                                  | labour consumption | H  | 0    | 5    |
|                                  | vehicle operation | Km | 427  | 436  |
| Total                            | labour consumption | H  | 36   | 9    |
|                                  | machine performance | Eh.| 10   | 9    |

*Eh. – engine hours

Gravity sewerage system showed a lower number of failures than the vacuum one during the monitored time period. The reason is that gravity sewerage system is less prone to negative impacts on its basic functionality due to the occurrence of failures or accidents of the sewerage sections. In case of vacuum sewerage system, the occurrence of a failure is usually detected immediately because of the loss of vacuum and limited waste water transport function. Objectively, it is necessary to note that common vacuum sewerage system failures are not demanding in terms of the consumed material and do not require special machinery or equipment.

3.3. Direct costs
In the case of the sewerage systems, the assessment of the level of operating costs is important for at least two reasons. The first one is the fact that the sewerage system provides a public service and the price for this service, according to the generally accepted rules, should not exceed the socially tolerable limits. The second reason is the relatively long service life of the whole system. A decision to
select a particular drainage method is a commitment to continued maintenance and operation of the system for decades, and it is almost impossible to change the entire functional system.

Table 2 clearly shows that the level of direct operating costs of the assessed vacuum and gravity sewerage system is comparable in terms of the direct costs.

| Cost group                        | Vacuum sewerage system | Gravity sewerage system |
|-----------------------------------|------------------------|-------------------------|
|                                   | year 2015              | year 2016               | year 2015 | year 2016 |
| Material for repairs              | CZK                    | 756.00                  | 1 030.00 | 66 111.00 | 1 974.00 |
| Electric energy                   | CZK                    | 122 480.00              | 147 104.00 | 28 350.00 | 34 322.00 |
| Sewerage system repairs           | CZK                    | 15 892.00               | 16 981.00 | 15 100.00 | 4 998.00 |
| Personal costs                    | CZK                    | 102 626.00              | 104 372.00 | 88 658.00 | 81 480.00 |
| Transportation                    | CZK                    | 65 926.00               | 65 342.00 | 71 443.00 | 74 721.00 |
| Laboratory analyses               | CZK                    | 3 120.00                | 3 120.00 | 118 192.00 | 123 609.00 |
| **Total**                         | **CZK**                | **312 815.00**          | **339 965.00** | **389 869.00** | **323 120.00** |

### 4. Recommendation for the operation of a vacuum sewerage system

The operating recommendations can generally be divided into several areas, namely improving the awareness of the sewerage system users, building modifications of the vacuum sewerage system elements, suggestions concerning the maintenance changes and addition of a monitoring system.

#### 4.1. Improving the awareness of sewerage system users

A significant share of the vacuum sewerage system failures and accidents is caused by the presence of undesirable objects (wet napkins, diapers, feminine hygiene products, textile pieces, etc.) in waste water. In order to sufficiently eliminate the problematic content of waste water and to improve the awareness of its producers, it is necessary to carry out a regular information campaign.

#### 4.2. Building modifications of vacuum sewerage system elements

Freezing of the suction valves and control centres during the winter months is a major problem. The cause usually arises during the construction of a vacuum system, where the installation of the aeration pipelines on the gravity parts of the sewerage connections was not carried out, the aeration pipeline of the vacuum suction valve may be missing on the collection sump and the air is fed directly from the collection sump. It is advisable to add air intake pipelines to all the gravity parts of the sewerage system connections. This measure eliminates the need of the producers to provisionally suck air into the collecting shaft and the cause of the suction valves and control centres freezing during the winter period. The collecting shafts, which have not been equipped with an air supply pipeline for controlling and securing the cyclical opening and closing of the suction valve during the building of the sewerage system, must be completed by adding this construction.

#### 4.3. Suggestions concerning maintenance changes

The maintenance of the selected problematic collecting shafts should be carried out once a year, in order to increase the efficiency and reliability, and in the case of other collecting shafts, it should be done continuously every four years. This intervention should, in addition to the inspection and cleaning of all parts of the collecting shaft, also include a removal of the suction valve and the control centre, cleaning and inspection of all the pipelines and hoses, the installation of another vacuum suction valve and control centre, which were dismantled, cleaned and lubricated in the workshop before.

#### 4.4. Adding a monitoring system

Achieving a consistently high level of vacuum sewerage system service is not possible without high-quality and useful information. The highest availability and informative value is associated with the
data that can be obtained in real time and that include information about sufficiently large location and about the possible links.

5. Conclusion
The main problem related to the operation of a vacuum sewerage system is the frequency of failures and the high consumption of resources necessary for their identification. The analysis helped us to identify the most serious causes of the occurrence of emergency situations, such as the design deficiencies arising during the sewerage system construction, the presence of material in the transported waste water which cannot be discharged into the sewerage system according to the valid rules, and the incorrectly performed preventive maintenance of the suction valves. High consumption of resources necessary to solve the failure situations is also caused by the insufficient range of the collected operational records and their low informative value or by not using new technologies in the field of measurement and remote monitoring of the vacuum level and suction valve function.

Under suitable conditions, vacuum sewer system does not have higher requirements with respect to the inevitable operating costs and the necessary resources of the operator. Since this is a system of alternative way of waste water transportation to gravity sewerage system, one has to bear in mind that the meaning of the word alternative does not mean a general full-fledged substitution of the gravity sewerage system, but it offers another possibility of transporting waste water in locations where the conditions for the use of a gravity sewerage system are not favourable.

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