Fouling of in-sewer heat exchangers: to oversize them or to clean them?

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Abstract
In-sewer heat exchangers are subject to fouling reducing heat transfer efficiency. Biofilm growth and renewal after mechanical cleaning as well as probability of biofilm scouring by storm events were studied by combination of biofilm sampling and shear stress modelling. The amount of biofilm decreases with increasing shear untouched tress in the sewer. In sewers with high shear stress (25-32 N/m^2) cleaning has no effect as biofilm renewal occurs in less than 2 weeks. In sewers with lower shear stress (4-6 N/m^2), cleaning 1 per 2 weeks reduces the amount of biofilm and sediments to about a half. Self-cleansing of heat exchangers during storm events can substitute the cleaning only in summer and in a very limited number of sewers. Cost analysis showed that the smaller the heat exchanger area, the better the strategy to oversize it than to clean it. The necessary oversizing can be derived for a given heat exchanger type and cleaning costs.

Keywords
biofilm; costs; self-cleansing; shear stress; sewer system

INTRODUCTION

One of the future scenarios of urban drainage system developments targets increased pressure at energy recovery from the wastewater. Thus, heat exchangers utilizing wastewater as an energy source are going to become more frequent, especially for combination of winter heating and summer cooling. However, in-sewer heat exchangers are subject to fouling caused by bacterial biofilms and sediments, which can lead to a reduction of the heat transfer efficiency up to 50% (Wanner, 2006). That requires the heat exchangers to be either efficiently cleaned or oversized.

Important questions have not been answered sufficiently, yet, such as:

- How often do heat exchangers in combined sewers have to be cleaned to maintain reasonable heat transfer efficiency? Does the necessary cleaning frequency vary for different hydraulic conditions?
- Could biofilm scouring during storm events be sufficient for the heat exchangers self-cleansing?
- Can the extent of fouling of the heat exchanger at a given installation site be anticipated? Can a strategy based on a-priori knowledge be developed as to the maintenance schedule or the percentage of the oversizing of the heat exchanger?

The paper gives first answers to the above questions.

METHODS AND MATERIAL

In-sewer biofilm sampling

In-sewer biofilm both from regularly mechanically cleaned (1 per 2 weeks) and untouched parts of metal plates (300 cm^2) installed in two combined sewers in Prague and exposed to different hydraulic conditions (dry weather shear stress 25-32 N/m^2 and 4-6 N/m^2, respectively) was sampled to study the amount, variability and renewal of the biofilm and the cleaning efficiency. The biofilm samples were analysed for total suspended solids (TSS) and total volatile solids (TVS).

Heat exchangers self-cleansing analysis

Rainfall-runoff simulations with a hydrodynamic model (MIKE URBAN) for a 10-years rainfall series were performed in a pilot catchment (Stransky et al., 2014) in order to obtain velocities and shear stress values in sewer reaches being potential heat exchangers installation sites. Probability of self-cleansing during storm events was evaluated for different sewer self-cleansing criteria based on literature (Reiff, 1991; Ashley, 1992; Pisano et al., 1998; Huisman, 2001; Wanner, 2004, Guzman, 2007) and on own observations (shear stress 2.5, 7, 15 and 25 N/m^2 of the minimum duration 5 and 20 minutes and frequency 1 per 2 weeks).

Cost analysis

Costs of different scenarios of heat exchangers oversizing and maintenance frequency were analysed. Investment costs of the additional heat exchanger surface area cover production costs and installation costs including discharge diversion costs related to the heat exchanger length. Maintenance costs comprise both fixed travel and personal costs and personal costs dependant on the heat exchanger area. The annual maintenance costs are given by the cleaning frequency. They must be evaluated for the heat exchanger lifetime period and discounted:

$$C_d(T) = C(T)\frac{(1+r)^T - 1}{r \cdot (1+r)^T}$$

$C_d(T)$	discounted maintenance costs over the lifetime period T
$C(T)$	maintenance costs over the lifetime period T
r	discount factor

RESULTS AND DISCUSSION

Biofilm amount and cleaning efficiency

High shear stress. In the sewer with high shear stress the amount of biofilm at both the cleaned and untouched sites was almost the same and exhibited only a slight variation (8.6±0.9 g TVS /m^2 and 8.1±2.0 g TVS /m^2, respectively). No effect of cleaning and of rainfall events on the amount of biofilm was observed (Figure 1).

Low shear stress. On contrary, in the sewer with lower shear stress the cleaning maintained quite stable amount of biofilm of 15.8±4.0 g TVS /m^2 whereas the amount of biofilm at the untouched sites was approximately double (28.3±14.4 g TVS /m^2) and was subject to a higher variation. Samples contained up to 80% of inorganic matter. The cleaning exhibited a higher influence on the sediment removal than on the biofilm removal (40.5±27.0 g TSS /m^2 and 87.2±59.0 g TSS /m^2 at cleaned sites and at untouched sites, respectively) (Figure 2).

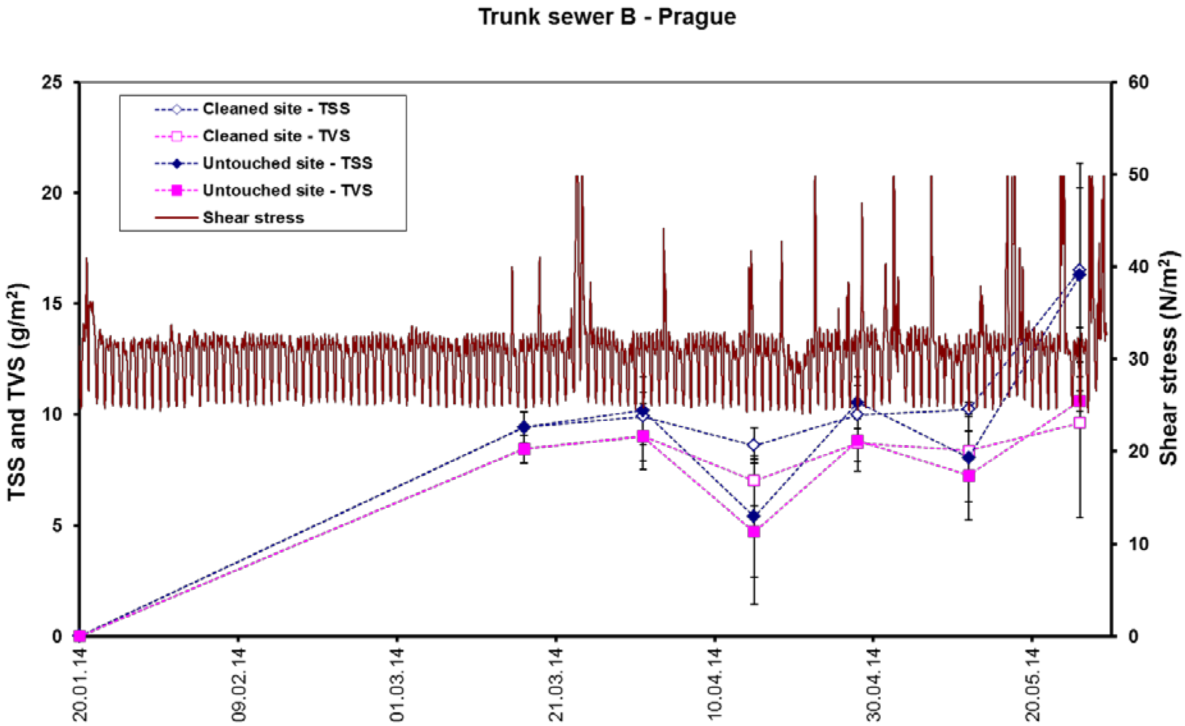

Figure 1. Biofilm amount at cleaned and untouched sites in a sewer with high shear stress

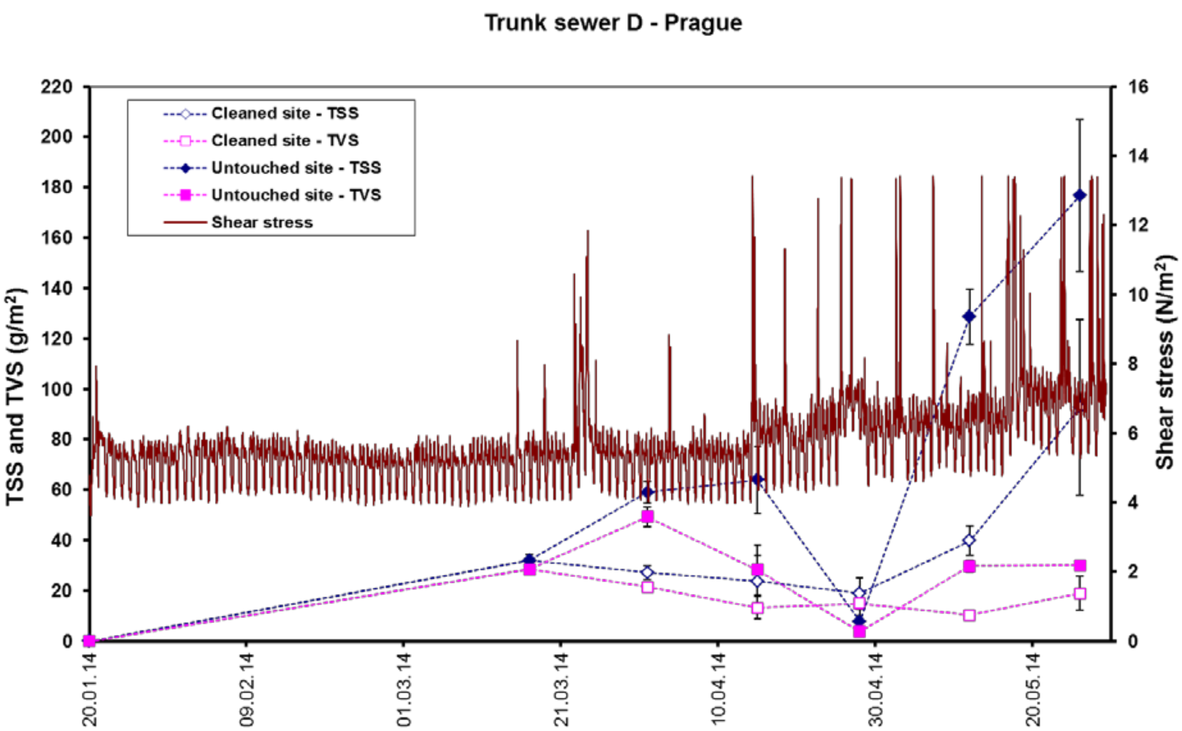

Figure 2. Biofilm amount at cleaned and untouched sites in a sewer with lower shear stress

Heat exchangers self-cleansing

The self-cleansing probability is determined by the rainfall distribution over the year (Figure 3). The criterion of the increased shear stress duration is of a minor importance than its frequency as the increased shear stress usually occurs for a longer time than 20 minutes. In the period 09-04, no sewer reaches being potential heat exchanger installation sites in the pilot catchment comply the most stringent self-cleansing shear stress criterion (25 N/m^2) and only 4% of the reaches suit the least stringent criterion (2.5 N/m^2). Thus, no self-cleansing can be counted on in the heating season (09-05). In the cooling season (06-08) up to 17% of the heat exchangers might be subject to self-cleansing, however, in case the most stringent criterion is valid, this number reduces to only 1%.

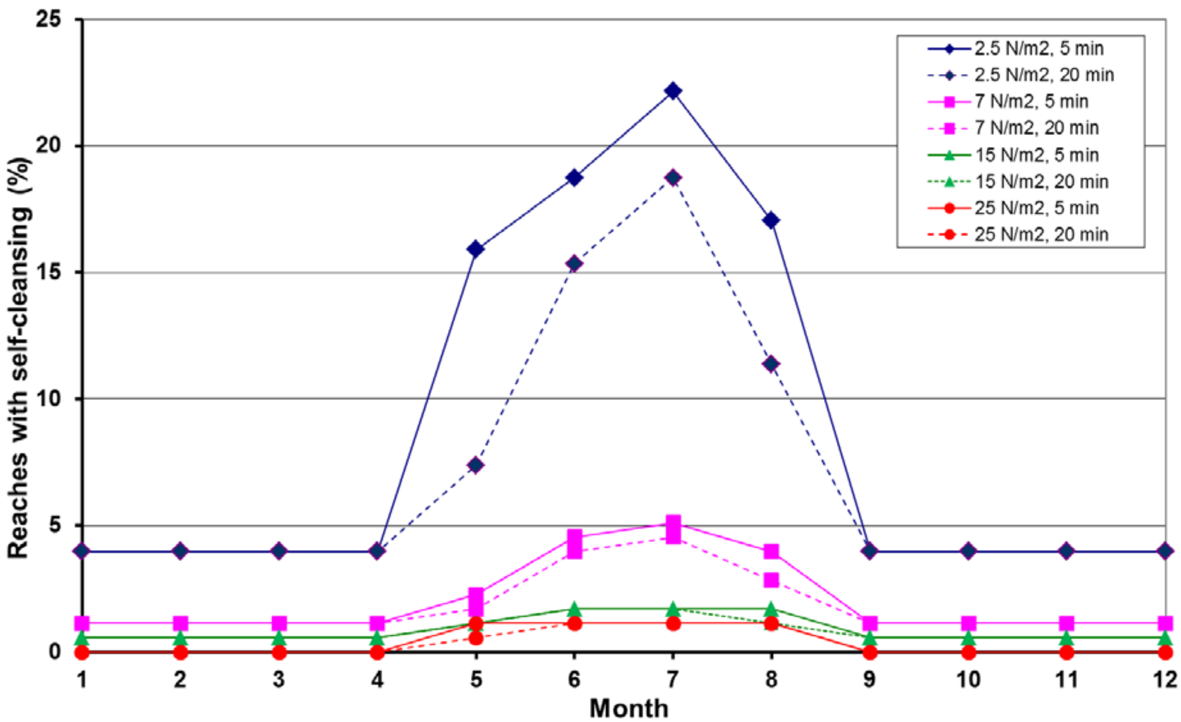

Figure 3. Evaluation of the self-cleansing possibility of heat exchanger installation sites in the pilot catchment

Cost analysis

To keep a certain heat transfer efficiency, the necessary cleaning frequency determines the percentage of the heat exchanger surface area oversizing cheaper than the cleaning costs during its life span. For the heat exchanger developed (Stransky et al., 2014) (expected lifetime 40 years, discount factor 0.05), up to 270% oversizing might be more favourable for the smallest heat exchangers than the cleaning frequency 1 per 2 weeks (26/year) (Figure 4). The advantageousness of oversizing decreases with the heat exchanger area and stabilizes at about 100%; for low cleaning frequency (4/year) at about 15%.

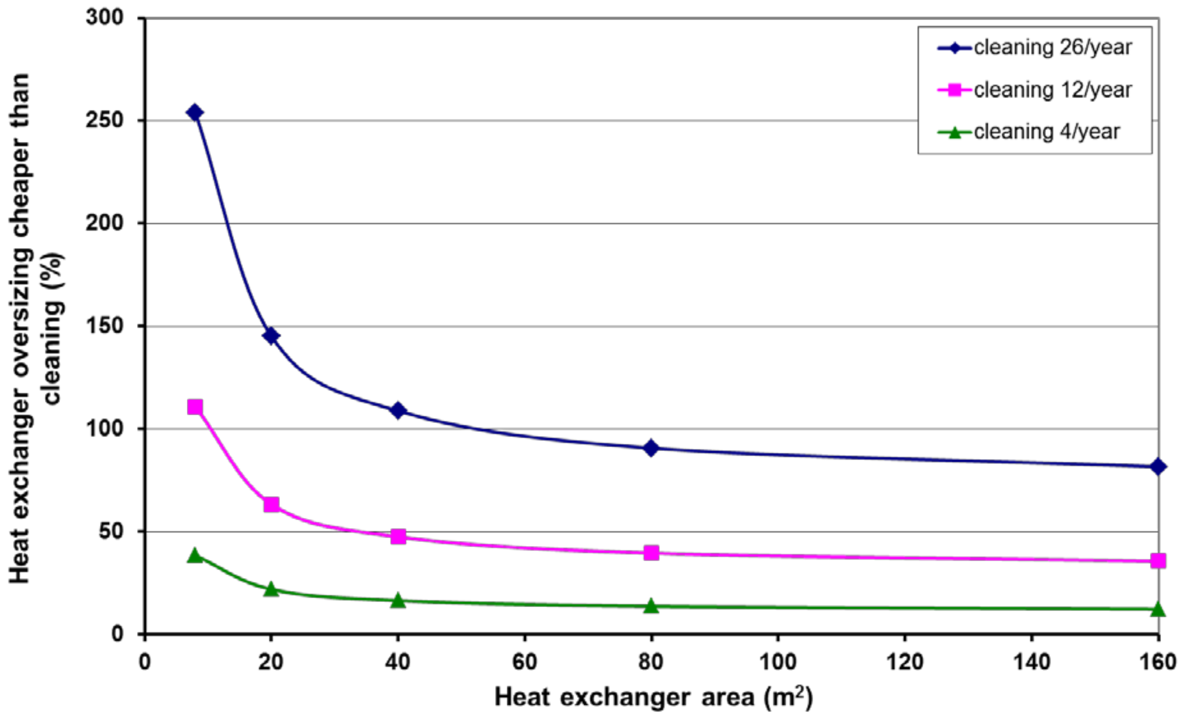

Figure 4. Percentage of the heat exchanger area oversizing cheaper than cleaning

CONCLUSIONS

Key findings can be summarized as following:

- The amount of biofilm decreases with increasing shear stress in the sewer. In sewers with high shear stress (25-32 N/m^2) and small biofilm amount, the heat exchanger cleaning is not necessary and/or efficient as the biofilm renewal occurs in less than 2 weeks. In sewers with lower shear stress (4-6 N/m^2), cleaning 1 per 2 weeks reduces the amount of biofilm and sediments to about a half. Thus, fouling of in-sewer heat exchangers cannot be avoided even by very frequent cleaning, however, it can be kept in reasonable limits.
- Self-cleansing of heat exchangers during storms events can substitute the cleaning only in summer and in a very limited number of sewers (however, this depends on the locality).
- The smaller the heat exchanger area, the better the strategy to oversize it than to clean it. The necessary oversizing can be derived for a given heat exchanger type and cleaning costs.
- For proper heat exchanger design, discharge and temperature at the installation site should be monitored. We recommend to determine also the shear stress in the sewer to get an idea of the expected biofilm amount and/or to test the cleaning strategy on in-situ biofilm samples grown on the heat exchanger material.

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