Benefits of reducing toilet flushing volume in terms of resource recovery from blackwater

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INTRODUCTION

Source separating sanitation and subsequent recovery of nutrients are gaining an increasing popularity (Langergraber and Muellegger 2005; Larsen et al. 2009; Zeeman and Kujawa-Roeleveld 2011). The major feature of source separation is that a majority of nutrients and organic matter is retained in the relatively high concentrated blackwater fraction (Todt et al. 2015). This opens for the application of novel anaerobic treatment approaches having a high energy efficiency compared to traditional technologies. However, especially when heat disinfection is integrated to eliminate pathogens, energy efficiency of blackwater resource recovery becomes highly dependent on the concentration of its organic matter content (Zeeman and Kujawa-Roeleveld 2011). The latter is mainly determined by the flushing volume of the toilet (Todt et al. 2015).

This study was investigating the impact of flushing volume as well as toilet type on the energy balance of an anaerobic treatment approach. The energy balance considers a UASB reactor unit followed by a heat disinfection unit. Energy recovery from methane is calculated for both a simple heat recovery via a gas burner and a more advanced conversion into heat and electricity in a gas turbine (Fig. 1).

RESULTS AND DISCUSSION

The gross energy consumption was calculated for five types of toilets having different flushing volumes (Tab. 1). Gravity toilets do not need energy but have with 2-5 litre a relatively high flushing volume. To obtain a lower flushing volume, a vacuum sewer system is needed giving a trade-off in an electrical energy consumption for blackwater transportation. A UASB needs both heat energy to reach an optimal process temperature and electrical energy for feeding that are both considered to be volume dependent. For disinfection an additional up-heating to 60-70 °C is needed which again requires accordingly additional heat energy.

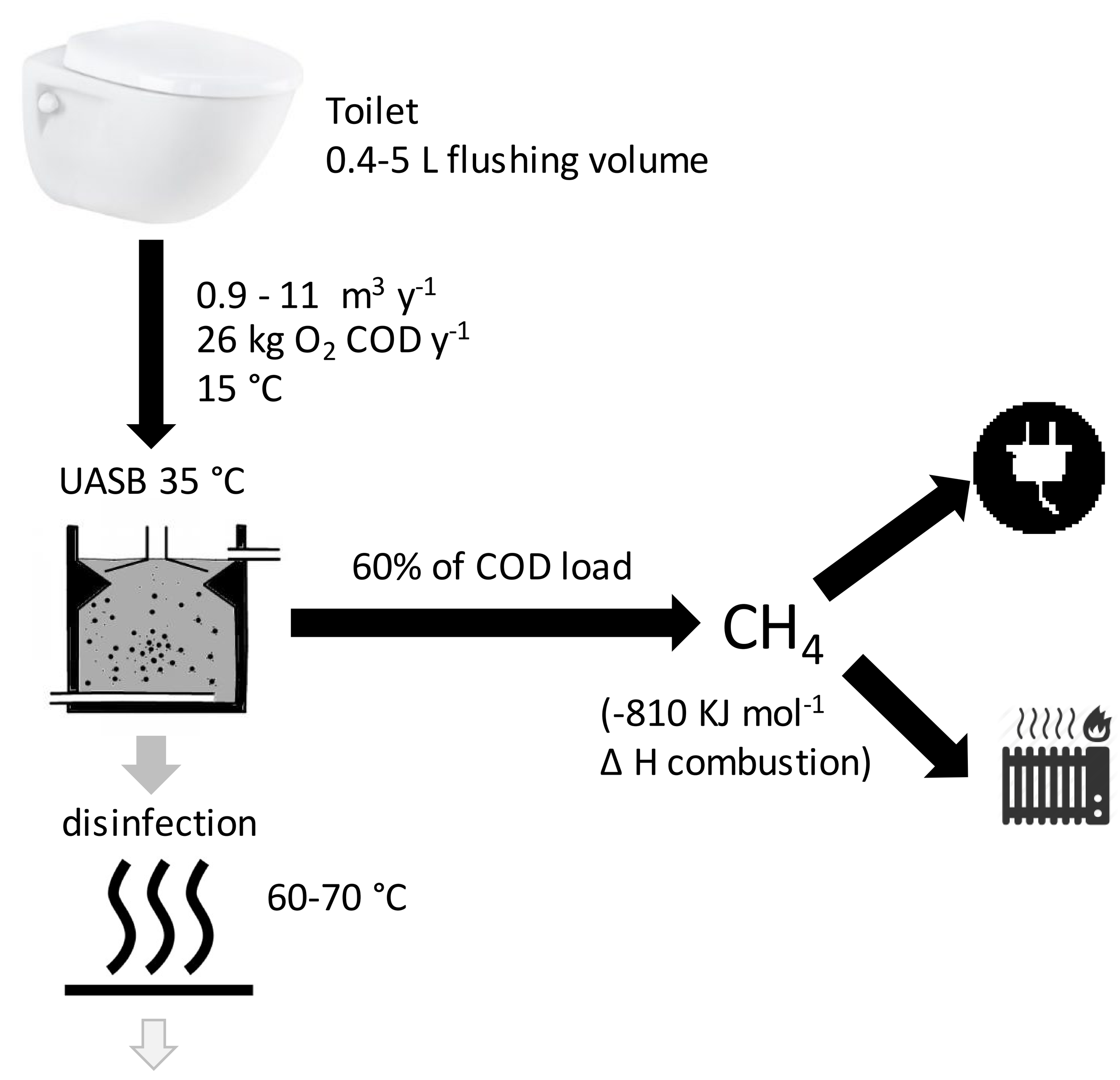

Figure 1: Processes and basic conditions applied for energy assessment of this study

Given the thermal physics of fluids, heat energy requirement is more or less linear dependent on the flushing volume (Tab. 1). Electrical energy requirement on the other hand is higher for the lowest flushing volumes due to the additional energy consumption of the vacuum system. The latter accounts for approximately 10 kWh y^{-1} per capita (Todt and Jenssen 2015) and is mainly depending on the number of pump starts or flushing events, respectively, rather than the flushing volume itself. Hence no significant difference in electrical consumption was found for the three vacuum-based toilet types.

Considering a typical CH_4 conversion accounting for 60% of COD load for a UASB reactor (Zeeman and Kujawa-Roeleveld 2011) and burner efficiency of 80% of $_{\Delta}H$ combustion, 43 kWh heat energy could be gained from the organic matter contained in the blackwater with a simple gas heating system. This accounts for 6-73% of the heat needed for operation of UASB and disinfection stage (Fig. 2). Applying a more advanced recovery would gain 16 kWh y^{-1} electrical power and 27 kWh y^{-1} heat, considering the energy transformation efficiencies for a gas turbine reported by Kroiss and Svardal (2009).

Table 1: Energy consumption per capita (kWh y^{-1}) at different toilet flushing volumes for vacuum sewer and anaerobic blackwater treatment including disinfection unit

Toilet type, flushing volume	heat requirement	electricity requirement
Gravity standard, 5 L	703	19
Gravity low flush, 2 L	281	14
Vacuum standard, 1.2 L	169	22
Vacuum low flush, 0.6 L	94	21
Vacuum ultra-low flush, 0.4 L	59	21

Fig. 2 indicate an exponential decrease of net heat consumption with decreasing flushing volume, while electrical energy consumption slightly increases due to the vacuum sewer. However, since 75-95% of the systems energy consumption is heat, reducing the flushing volume from 5 to 0.4 liter reduces the net energy requirement from 680 to 80 kWh y-1. As shown in Fig. 2, at the lowest flushing volume up to 80% of the energy needed to run the system can be recovered, increasing the energy efficiency and recovery potential of a blackwater treatment notably.

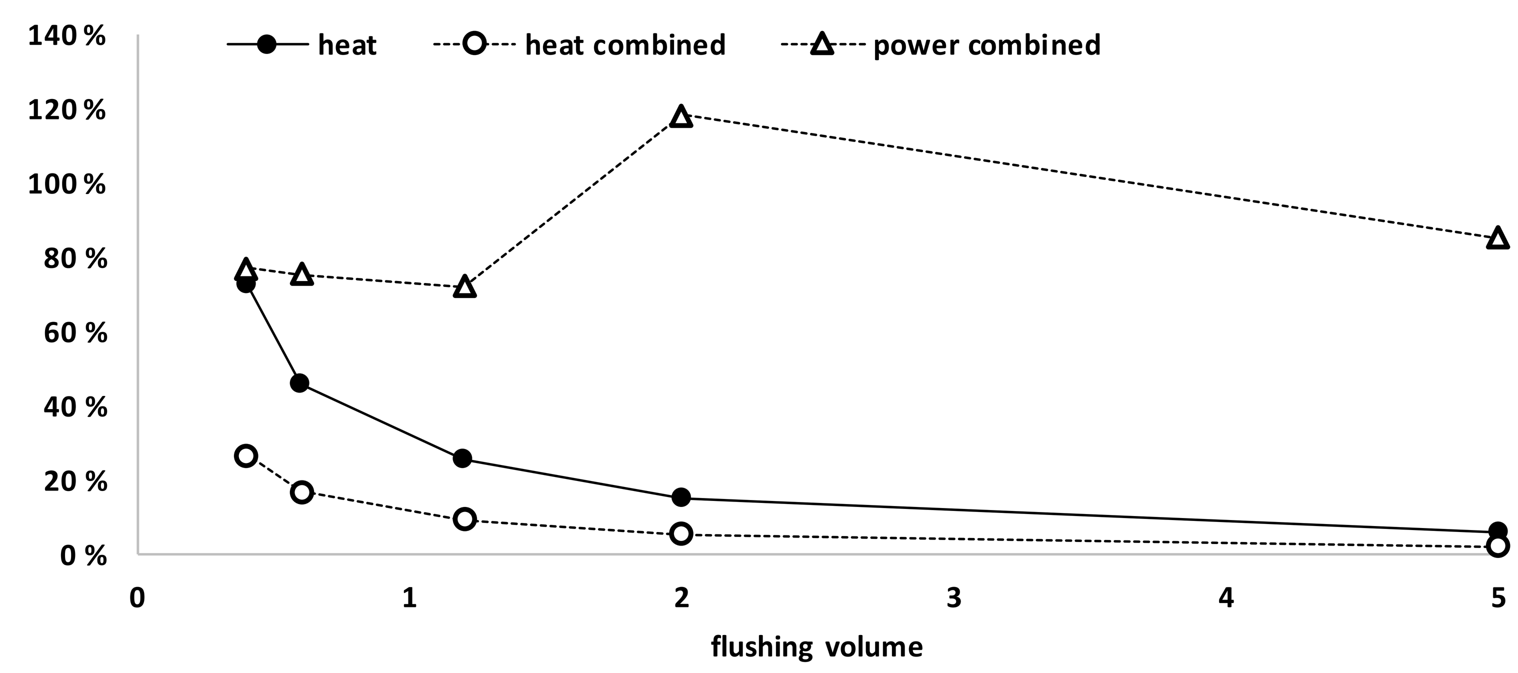

Figure 2: Energy recovery potential in percentage of process energy consumption in dependency of flushing volume for a simple (heat only) and advanced (heat/electrical combined) recovery system

CONCLUSIONS

- The external heat energy needed to run a treatment and disinfection process increases exponentially with increasing toilet flushing volume
- Decreasing the flushing volume from 5 to 0.4 liter reduces the net heat consumption for toilet operation, organic matter removal and disinfection on 88% from 680 to 80 kWh $capita^{-1}\ y^{-1}$
- Up to 80% of energy needed for toilet operation, organic matter removal and disinfection can be recovered at a flushing volume of 0.4 liter

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