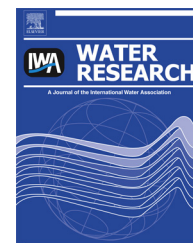


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A mathematical model to predict the effect of heat recovery on the wastewater temperature in sewers

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ABSTRACT

Raw wastewater contains considerable amounts of energy that can be recovered by means of a heat pump and a heat exchanger installed in the sewer. The technique is well established, and there are approximately 50 facilities in Switzerland, many of which have been successfully using this technique for years. The planning of new facilities requires predictions of the effect of heat recovery on the wastewater temperature in the sewer because altered wastewater temperatures may cause problems for the biological processes used in wastewater treatment plants and receiving waters. A mathematical model is presented that calculates the discharge in a sewer conduit and the spatial profiles and dynamics of the temperature in the wastewater, sewer headspace, pipe, and surrounding soil. The model was implemented in the simulation program TEMPEST and was used to evaluate measured time series of discharge and temperatures. It was found that the model adequately reproduces the measured data and that the temperature and thermal conductivity of the soil and the distance between the sewer pipe and undisturbed soil are the most sensitive model parameters. The temporary storage of heat in the pipe wall and the exchange of heat between wastewater and the pipe wall are the most important processes for heat transfer. The model can be used as a tool to determine the optimal site for heat recovery and the maximal amount of extractable heat.

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1. Introduction

Wastewater released into the sewer from showers, sinks and washers is an attractive source of energy. It is permanently available almost everywhere, has temperatures of 10–20 °C throughout the year and contains considerable amounts of energy. If 1 m³ of water is cooled down by 1 °C, 1.16 kWh of heat energy can be gained. If in the city of Zurich, Switzerland, the dry weather wastewater discharge of 230,000 m³/s were continuously cooled down by 1 °C, the heat energy theoretically gained would correspond to a continuous delivery of 10 MW. At present, approximately 50 facilities are operating in

Switzerland, extracting heat from the wastewater by means of heat pumps and heat exchangers installed in the sewer; among these are three facilities in Zurich that produce a total power of 5 MW (EWZ, 2008). One of these facilities heats 800 apartments, and another heats and cools the largest building in Switzerland. There is a facility in Norway that heats and cools an entire district of the city of Oslo (Schmid, 2008).

Basically, there are two techniques to recover heat from the sewer. The conventional technique is to install a heat exchanger at the bottom of the sewer pipe. This technique is simple and well established, but the efficiency of the heat exchanger will be reduced drastically if its surface is covered

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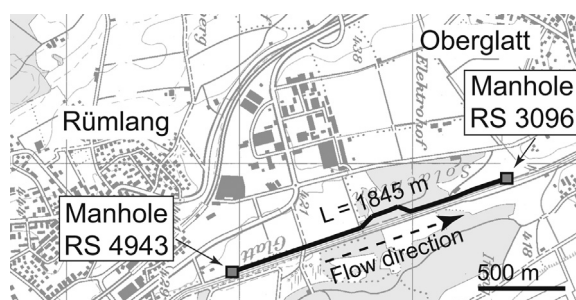


Fig. 1 – Top view of a section of the sewer between the villages of Rümlang and Oberglatt in the Canton of Zurich, Switzerland.

by sediments or biofilms or is not completely submerged. An alternative and newer technique is to pump the wastewater through a heat exchanger installed outside the sewer. This technique makes it easier to control fouling of the heat exchanger, but it requires that the wastewater be filtered and leads to higher installation and pumping costs.

From an ecological point of view, it is logical to close energy cycles by bringing the energy back to the original user to re-use the energy disposed with the wastewater a second time instead of warming the environment (Olsson, 2012). The economic competitiveness of heat extraction from wastewater depends on the price of oil and gas, on the distance between the recovery site and the user of the energy and on the availability of alternative ambient energy sources (Chafghazi et al., 2010). Facilities using wastewater for both heating and cooling are usually very economical. However, there are legal constraints in most countries on the permitted temperature changes for influents of wastewater treatment plants and receiving waters (AWEL, 2010; Wanner et al., 2005). Therefore, successful planning and operation of heat recovery facilities require that their effect on the wastewater temperature be quantifiable.

In this paper, a model is presented to calculate the dynamics and spatial profiles of wastewater temperature in a sewer pipe as a function of wastewater discharge, airflow in the sewer and heat transfer between the sewer, soil and atmosphere. The model is implemented in the simulation program TEMPEST (temperature estimation) and is calibrated and

Table 1 – Overview of the information required to model the wastewater temperature in a sewer.

Parameter	Symbol	Value	Unit	Source ^a
Sewer pipe				
Length	L	1845	m	IP
Nominal diameter	D	0.9	m	IP
Friction coefficient ^{b, h}	k_{st}	70	$m^{1/3} s^{-1}$	L
Slope	S_0	0.0091	—	IP
Wall thickness	s	0.1	m	IP
Wall thermal conductivity ^{b, h}	λ_p	2.3	W/(mK)	IP/L
Wall thermal diffusivity ^{b, h}	a_p	$1 \cdot 10^{-6}$	m^2/s	IP/L
Soil				
Undisturbed temperature ^{e, h}	$T_{s,inf}$	5.5	°C	M/E
Penetration depth ^h	δ_s	0.1	m	E
Thermal conductivity ^{f, h}	λ_s	1.1	W/(mK)	IP/L
Thermal diffusivity ^f	a_s	$0.2 \cdot 10^{-6}$	m^2/s	IP/L
Wastewater				
Discharge at influent ^c	Q_{Win}	0.03	m^3/s	M
Temperature at influent ^c	T_{Win}	12	°C	M
COD degradation rate ^{d, h}	r_{COD}	2.8	$mgCOD/(m^3 s)$	E
Fouling factor ^h	f	200	$W/(m^2 K)$	L
Density ^g	ρ_w	998.2	kg/m^3	L
Thermal conductivity ^g	λ_w	0.60	W/(mK)	L
Specific heat capacity ^g	$c_{p,w}$	4181	J/(kg K)	L
Air				
Ambient temperature ^c	T_A	8.3	°C	W
Ambient pressure ^c	p_A	966	mbar	W
Ambient relative humidity ^c	φ_A	0.75	—	W
Density	ρ_L	1.19	kg/m^3	L
Thermal conductivity	λ_L	0.0257	J/(kg K)	L
Specific heat capacity	$c_{p,L}$	1007	J/(kg K)	L

^a Key: IP = implementation plan, E = estimate, L = literature, M = field measurement and W = weather station.

^b Typical parameter for concrete reinforced with 1% steel (e.g., Hager (2010) for friction coefficient and DIN (2000) for thermal properties) selected according to the implementation plan.

^c Average during calibration period.

^d Based on studies by Huisman et al. (2004) and Flamink et al. (2005).

^e Estimate based on measurements with temperature probes buried in the soil.

^f Typical parameter for clay (Unsworth and Monteith, 1990), which is prevalent according to the implementation plan.

^g Physical properties of wastewater approximated by clean water values at 10 °C.

^h Parameter subject to calibration.

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