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Analysing wastewater temperature development in a sewer system as a basis for the evaluation of wastewater heat recovery potentials

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ABSTRACT

Wastewater contains significant quantities of thermal energy. Consequently, heat recovery in sewer systems can provide urban areas with an additional source of renewable energy for heating of buildings. However, certain treatment processes in a wastewater treatment plant are temperature-sensitive. From a water protection perspective it is therefore imperative, that heat recovery in sewer systems does not negatively affect the performance of the wastewater treatment. With regard to practical implication the question arises, where to find the locations best suitable for wastewater heat recovery in sewer systems. Hereby, suitability is characterised by meeting both the energy supply and water pollution control requirements. This article introduces a methodological framework (procedure) to evaluate the suitability of a potential heat recovery site integrating both perspectives. The framework incorporates decision support criteria and planning principles for energy planners and water authorities. Application in a case study proved practicability of the procedure as well as of the criteria and principles. In addition, it also delivered comprehensive information on the spatial and temporal wastewater temperature development in the regarded sewer system.

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1. Introduction

In order to counteract climate change the European Union has committed to decreasing greenhouse gas emissions by 40% compared to the level in 1990 until 2030 alongside an increase in the share of renewable energy to at least 27%. Furthermore, the Energy Roadmap 2050 aims on reducing greenhouse gas emissions by 2050 by over 80% (European Commission [1]). Reducing greenhouse gas emissions also represents a key element of the Paris Agreement reached at the recent UN Climate Change Conference [2]. One of the areas, where the use of renewable energy is promoted, is heating and cooling of buildings (European Parliament and council of the European Union [3]). A technology that is addressed in connection with this is capturing the thermal energy contained in wastewater and using it for heating (McCarty et al. [4]), (Nowak et al. [5]), (Frijns et al. [6]). This approach requires two technical components: a heat exchanger, which is directly placed in the wastewater flow, and an electrically driven heat pump situated in a heating station outside the sewer system. Both components are connected by a pipe system containing a circulating heat transfer fluid. This fluid absorbs heat from wastewater. The heat pump raises this heat to an even higher level of temperature. Finally, the recovered and boosted heat is given off to a domestic heating system. Worldwide, at least 500 applications exist today (Schmid [7]) and many of them are located in Switzerland, Germany and Scandinavia (Hepbasli et al. [8]). It can be assumed that thermal use of wastewater will further increase in the next years as more and more countries include this energy source into their national energy policy. In Austria, for instance, heat recovery from wastewater is stated explicitly in the new release of the Federal Law on the Increase of Energy Efficiency (EEffG [9]).

Basically, there are three different locations for recovering thermal energy from wastewater, one being inside of a building, another option is in the sewer system (both locations are roughly clustered as upstream of the wastewater treatment plant (WWTP)) and the third is in the effluent of the WWTP (Culha et al. [10]). Each location has advantages and disadvantages (DWA [11]), Kretschmer and Ertl [12], Koch et al. [13]. Due to their location at the end of a sewer system wastewater quantities reach a maximum in the effluent of WWTPs. Consequently, this location contains a significant amount of thermal energy. For Austria, the usable thermal energy potential from this location is estimated at around 3200 GWh/a (Neugebauer et al. [14]). For upstream (in-sewer) heat recovery locations comparable estimations do not exist so far. However, heat recovery in sewer systems can also be promising as this location usually provides one major advantage: availability of potential consumers in very close vicinity to the heat source. This can be regarded as a key issue when considering practical application of this technology, as

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short transport distances in heat supply systems are essential in terms of economical implementation and operation. However, one major drawback of this location are potential negative effects on the temperature-sensitive treatment processes in a WWTP due to the cooling of wastewater. Therefore, durable and broadly accepted implementation planning must not only consider issues of energy economy, but also pay great attention to wastewater temperature related concerns, for which a more comprehensive understanding of wastewater temperature development in the sewer is necessary.

Today, wastewater temperature measurements usually are only available for WWTPs as they are part of a regular monitoring process (Council of the European Community [15]). But only little is known about wastewater temperature development in sewers as in-sewer measurements usually focus on flow rates required for real-time control (Fuchs and Beeneken [16]) and combined sewer overflow (CSO) management (Gruber et al. [17]). The few temperature related studies of sewer systems in international literature either concentrate only on small sewer sections of less than 2000 m (Abdel-Aal et al. [18], Schilperoort and Clemens [19]) or involve rather small numbers of in-sewer measuring points in bigger catchments (Bischofsberger and Seyfried [20], Cipolla and Maglionico [21]). Therefore, comprehensive wastewater temperature profiles for main sewer lines almost do not exist and knowledge about large scale system behaviour is still very scarce today.

At the moment, two models for estimating wastewater temperature development in the sewer and, therefore, for predicting changes in wastewater temperature at the inlet of a WWTP can be found in international literature (Abdel-Aal et al. [18], Dürrenmatt and Wanner [22]). Both models intend to support the evaluation of appropriate locations for heat recovery in sewer systems by calculating wastewater temperature development along the flow direction and over time. Basically, these tools seem promising as they reproduce the wastewater temperatures measured in the investigated sewers (under certain conditions). However, lateral inflows to the sewer system represent a current weakness of the models. Temperature and flow rate of lateral inflows (household connections, sub-catchments, etc.) have a major influence on the wastewater temperature in a sewer system, but comprehensive measurement of these data seems not economically feasible. Therefore, assumptions have to be made in the model set-up. Practical testing of one of the models mentioned above showed that satisfactory modelling results could only be achieved for sewers without lateral inflows (Steinmetz et al. [23]). The second model mentioned does not consider lateral inflows at all at the moment (Abdel-Aal et al. [18]). Due to these constraints the practical application of temperature modelling in sewer systems for the evaluation of appropriate heat recovery sites from a wastewater perspective seems to be rather limited from a present point of view. Consequently, there is a need for alternative methods to assess actual impacts of heat recovery in a sewer on the inflow temperature of a WWTP. Swiss and German national guidelines (Koch et al. [13], DWA [11], Buri and Kobel [24]) already describe simple calculation approaches to approximate the impact on WWTP inflow temperature and to estimate the available wastewater heat potential. Based on these fundamentals this article introduces a methodological framework (procedure) to evaluate a general suitability of potential heat recovery sites in a sewer system considering not only wastewater but also energy supply perspectives. In addition, the framework is complemented by decision support criteria and planning principles serving two purposes: on the one hand preidentification of promising heat recovery sites in sewer systems, and on the other hand wastewater related decision making based on in-sewer wastewater temperature development. Practical application of the procedure and verification of the decision support criteria and the planning principles will be implemented on available data from an in-sewer measurement campaign with significant spatial and temporal extension.

2. Materials and methods

The introduced methodological framework (procedure) for the evaluation of the suitability of a certain sewer location for heat recovery interlinks two different assessment approaches: evaluation of the available heat potential and evaluation of the impact of heat recovery on the wastewater temperature at the inlet of the WWTP. These approaches are integrated in the evaluation procedure, which is divided in four subsequent steps: First, a preselection of a potential heat recovery site has to be made in the related sewer system. Certain decision support criteria aid the process of preselection. Second, wastewater flow and temperature data from the potential site have to be processed for further use in the evaluation process. Data processing thereby comprises data collection (in-sewer measurements) as well as appropriate data preparation. Third, the processed data serve as an input for the assessment of the potential heat recovery site from an energy related and a wastewater related point of view. For this purpose two parameters are estimated: the available heat potential, and the potential impact on the wastewater temperature at the inflow of the concerned WWTP. Fourth, decision making addresses the comparison of heat demand and potential heat supply as well as the appraisal of the potential impact on the wastewater temperature in the inflow of the WWTP. The latter also incorporates several planning principles to support wastewater related decision making. The investigated site can be evaluated as suitable for heat recovery in sewer systems if heat demand is met with WWTP inflow temperature impacts remaining within tolerable limits. Fig. 1 gives a schematic representation of the methodological framework (procedure).

2.1. Preselection of a potential heat recovery site

The basic prerequisites for the suitability of in-sewer heat recovery are existing heat demand and available heat potential. Heat demand is basically determined by the type of use and the size of heated area, both data can be easily determined by expert energy planers (DWA [11]). The heat potential available at a specific site in the sewer system depends on the local wastewater flow and the wastewater temperature. As mentioned before, this information usually is not readily available, therefore, detailed investigations and measurements are inevitable. However, as a first reference value for potentially suitable heat recovery sites DWA [11] defines a minimum wastewater flow of 15 l/s (daily average). This value represents an upstream connection rate from 5000 to 10000 population equivalents. Based upon the relevant literature, the following wastewater temperature related aspects can be concluded: (a) wastewater temperature is highest at the first discharge point and decreases along the sewer system (Schilperoort and Clemens [19], Wanner et al. [25]) (b) Long wastewater flow paths in open terrain (uninhabited areas) result in a reduction of wastewater temperature (Steinmetz et al. [23]). (c) Wastewater temperature interacts with surrounding soil temperature and ambient air temperature (Abdel-Aal et al. [18], Dürrenmatt and Wanner [22], Steinmetz et al. [23]). (d) Soil temperature in urban areas is higher compared to open terrain (Tang et al. [26]). (e) The temperature level of lateral inflows is higher than in the main sewer line and has a dominant influence on wastewater temperature in the downstream sewer systems (Schilperoort and Clemens [19], Steinmetz et al. [23]). Based on the above, we derive four general but straightforward preselection criteria for the identification of potential wastewater heat recovery sites in sewer systems:

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