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Thermal Energy Recovery from Drinking Water

Jan Peter van der Hoek, Stefan Mol, Jawairia Imtiaz Ahmad, Gang Liu & Gertjan Medema

Abstract Waternet, the water utility of Amsterdam and surroundings, has the ambition to operate climate neutrally in 2020. Although large progress has been made since 1990 to reduce Greenhouse Gas emissions (GHG), in 2016 the remaining emission was still 37,203 ton CO2-eq. A possibility to further decrease the GHG emission is thermal energy recovery from drinking water. As Waternet produces drinking water from surface water, the temperature varies between 1 oC and 25 oC which offers opportunities. The question is whether thermal energy recovery from drinking water really results in a reduction in GHG emissions, and especially at what costs. In addition, thermal energy recovery influences the drinking water temperature and thus may affect the microbiological drinking water quality. A specific case in Amsterdam showed that cold recovery from drinking water contributes to the reduction of GHG emissions, and reduces the costs of cooling. Preliminary laboratory experiments revealed no negative effects on the microbiological drinking water quality.

Keywords: • cold recovery • Greenhouse Gas emissions • drinking water • microbiological water quality • thermal energy •

Correspondence Address: Jan Peter van der Hoek, Ph.D., Professor, Delft University of Technology, Department of Water Management, Stevinweg 1, 2628 CN Delft, The Netherlands, e-mail: j.p.vanderhoek@tudelft.nl. Stefan Mol, M.Sc., Researcher, Waternet, Department of Research & Advice, Korte Ouderkerkerdijk 7, 1096 AC Amsterdam, The Netherlands, e-mail: stefan.mol@waternet.nl. Jawairia Imtiaz Ahmad, M.Sc., Ph.D. Candidate, Delft University of Technology, Department of Water Management, Stevinweg 1, 2628 CN Delft, The Netherlands, e-mail: j.i.ahmad@tudelft.nl. Gang Liu, Ph.D., Associate Professor, Delft University of Technology, Department of Water Management, Stevinweg 1, 2628 CN Delft, The Netherlands, e-mail: g.liu-1@tudelft.nl. Gertjan Medema, Ph.D., Professor, Delft University of Technology, Department of Water Management, Stevinweg 1, 2628 CN Delft, The Netherlands, e-mail: g.medema@tudelft.nl.

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1 Introduction

Waternet is the public water utility of Amsterdam and surroundings. Waternet has the ambition to operate climate neutrally in 2020. A climate neutral operation is defined as an operation without a net greenhouse gas (GHG) emission. From 1990 to 2016 the GHG emission of Waternet decreased from 114,196 ton CO_2-eq to 37,203 ton CO_2-eq, as shown in Figure 1.

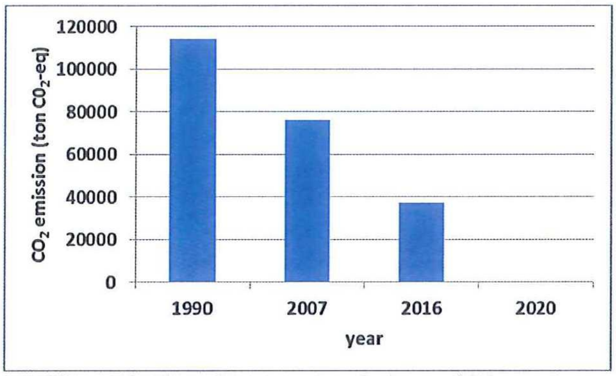

Figure 1. Greenhouse gas emissions of Waternet

Hence, additional measures have to be taken to realize the target in 2020. The policy of Waternet, and also a condition for the measures, is to select measures which can be incorporated in the operations of Waternet, and an inventory has been made recently [1]. An additional condition is that measures have to be cost neutral. One of the options concerns thermal energy recovery from drinking Water. As Waternet produces drinking water from surface water, which varies in temperature between 1 °C and 25 °C [2], cold recovery for cooling and heat recovery for heating, from drinking water transport pipes, looks attractive. In case of cold recovery, the drinking water temperature after cold recovery increases, which may affect the microbiological drinking water quality [3].

The objective of this study was to analyse the potential of cold recovery from drinking water on three decisive criteria: the effect on the reduction of GHG emission of Waternet, the financial effects and the effects on microbiological drinking water quality.

2 Materials and Methods

GHG emissions were calculated based on the international Greenhouse Gas Protocol [4]. To determine the effect of GHG emissions on the climate footprint, the Intergovernmental Panel on Climate Change Global Warming Potential (IPCC GWP) 100a method [5] was used. Within this method, only the environmental problem of climate change is evaluated and the results are expressed in CO_2 equivalents.

Costs of cold recovery from drinking water were based on the Total Costs of Ownership (TCO) concept, in which total costs of acquisition and operating costs as well as costs related to replacement at the end of the life cycle are included. The evaluation period covered a period of 30 years.

For the GHG analysis and the cost analysis a specific case was selected: the "Sanquin-Waternet" case. Sanquin produces plasma products from blood and needs cooling capacity to store products. Just along Sanquin a 700 mm drinking water main of Waternet passes. From this main a supply pipe and return pipe are connected with a heat exchanger, as shown in Figure 2.

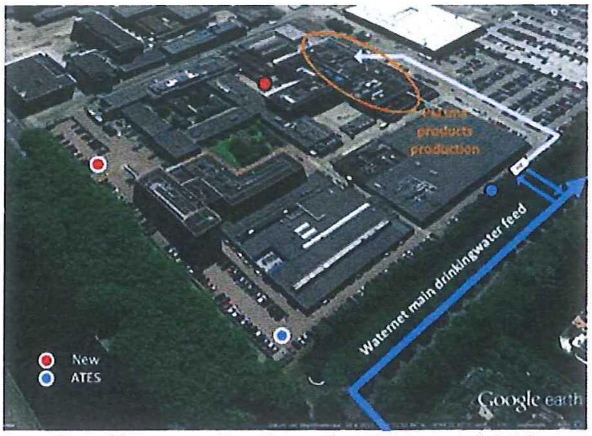

Figure 2. Delivery of cooling capacity, through a Waternet drinking water main, via a heat exchanger (HE), to Sanquin

Through this connection Waternet can supply Sanquin cooling capacity: during winter cooling capacity is delivered directly, and an aquifer thermal energy storage (ATES) is charged. In summer the ATES supplies the cooling capacity. Figure 3 shows the process set-up in winter and summer.

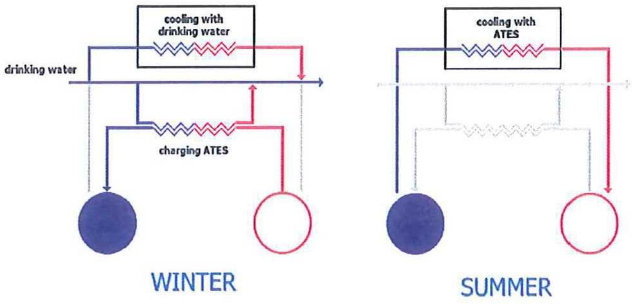

Figure 3. Process set-up of cooling with drinking water under winter and summer conditions

Effects on microbiological drinking water quality and biofilm formation were studied in three laboratory scale drinking water distribution systems (DWDS) [6]. Figure 4 shows the systems: system 1 is the study system with operational heat exchanger for cold recovery, system 2 is the control system with installed but not in operation heat exchanger to study the effect of additional surface area in the distribution system, while system 3 is the reference system without heat exchanger.

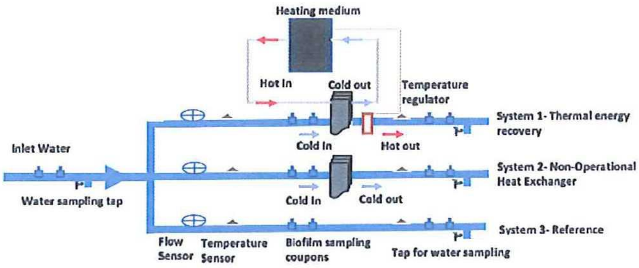

Figure 4. Laboratory scale drinking water distribution systems

Table 1 summarizes the operational conditions of the three laboratory scale systems. The systems were operated for a period of 6 months. As these preliminary laboratory experiments were carried out in the summer, the inlet drinking water temperature was relatively high (18-19 °C) compared to the inlet drinking water temperature at which the full-scale installation at Sanquin will be operated (temperatures below 15 °C).

Table 1. Operational conditions of the laboratory scale DWDS

	Laboratory scale DWDS		
	1	2	3
Flow rate (l/m)	4.5	4.5	4.5
Flow velocity (m/s)	0.15	0.15	0.15
Inlet temperature (°C)	19	18	19
Outlet temperature (°C)	24	18	19
Pipe material	PVC	PVC	PVC
Pipe diameter (mm)	25	25	25
Length of system (m)	10	10	10

Microbiological water quality and biofilm analysis concerned Total Cell Concentrations (TCC), Adenosine Tri Phospate (ATP) concentrations, *Aeromonas* spp. and *Legionella* spp..

3 Results and Discussion

3.1 Reduction of GHG emissions

The results with respect to reduction of GHG emissions in the Sanquin case are shown in Table 2. This table compares two situations: the use of conventional cooling machines for cooling capacity, and the use of drinking water for cooling capacity.

Table 2. Electricity use and GHG emission of two systems for cooling in the "Sanquin-Waternet" case

	Electricity use (kWh/year)	GHG emission (ton CO_2-eq/year)
Traditional cooling machines	2,000,000	1,220
Cooling with drinking water	200,000	120

Table 2 shows that in the case of cooling with drinking water, the GHG emission can be reduced with 1,100 ton CO_2-eq. The potential may be even higher when it is allowed to heat up the drinking water after the heat exchange above 15 °C. Until now the limit has been set at 15 °C for safety reasons. Research in the laboratory scale experiments have to reveal whether higher temperatures (without negative effects on microbiological water quality), and thus a higher GHG emission reduction, is feasible. In Amsterdam additional locations have to be found where thermal energy supply and demand matches and additional project can be realized to increase the contribution of thermal energy recovery in the target of 37,203 ton CO_2-eq.

3.2 Costs

The results with respect to the costs are summarized in Table 3. Based on the TCO, the system using cooling with drinking water has a lower TCO than the system using traditional cooling machines. Specific aspects, characteristic for the "Sanquin-Waternet" case, contribute to this. By using cooling with drinking water it is not necessary to extend the existing electricity infrastructure, and noise reducing measures are not required. In addition, traditional cooling machines require a footprint which is not available.

Table 3. Total costs of ownership of two systems for cooling in the "Sanquin-Waternet" case

	Total Costs of Ownership (million €)
Traditional cooling machines	8.0
Cooling with drinking water	5.4

3.3 Effect on microbiological drinking water quality and biofilm formation

Figure 5 shows the Total Cell Concentrations (TTC) and ATP concentrations in the bulk water phase in the laboratory scale DWDSs. The results reveal similar microbiological water quality in both systems with a heat exchanger (operational heat exchanger – system 1, and non-operational heat exchanger – system 2), before and after the heat exchanger, and in the reference system (system 3). This stable microbiological quality in the bulk water phase may be due to the short distance and retention time of the water (about one minute), which is too short for significant changes to occur.

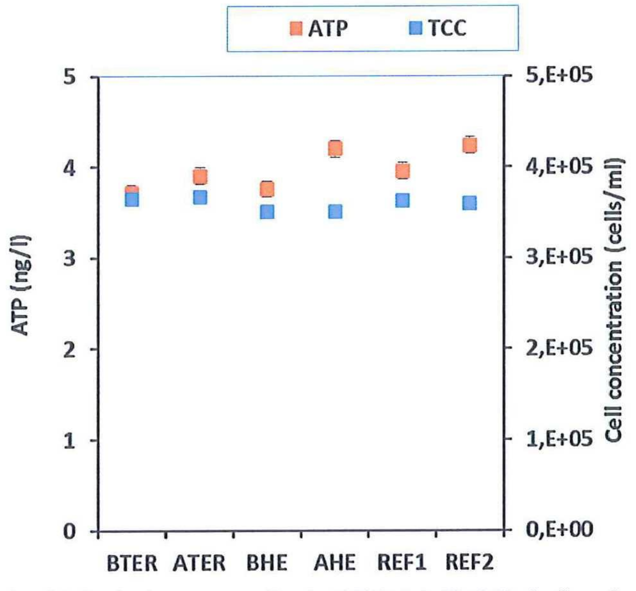

Figure 5. Microbiological water quality in DWDS 1 (BTER: before thermal energy recovery; ATER: after thermal energy recovery), DWDS 2 (BHE: before heat exchanger; AHE: after heat exchanger) and DWDS 3 (REF1: at start of DWDS; REF 2: at end DWDS) (n=29)

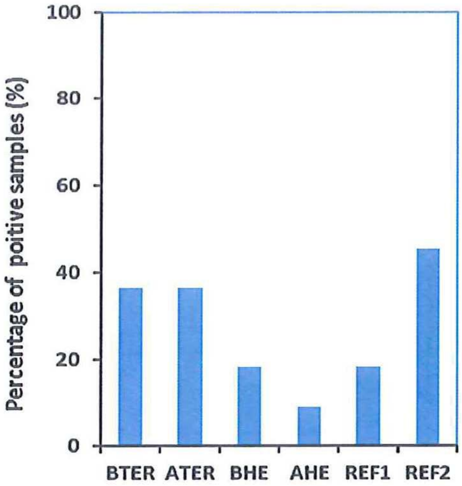

Figure 6. Positive *Legionella* spp. samples in bulk water in DWDS 1 (BTER: before thermal energy recovery; ATER: after thermal energy recovery), DWDS 2 (BHE: before heat exchanger; AHE: after heat exchanger) and DWDS 3 (REF1: at start of DWDS; REF 2: at end DWDS) (n=11)

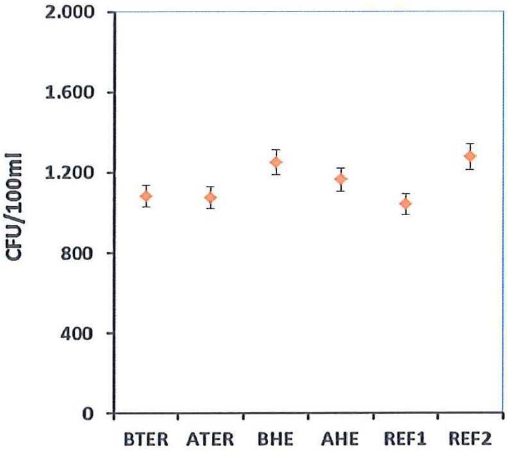

Figure 7. *Aeromonas* spp. in bulk water in DWDS 1 (BTER: before thermal energy recovery; ATER: after thermal energy recovery), DWDS 2 (BHE: before heat exchanger; AHE: after heat exchanger) and DWDS 3 (REF1: at start of DWDS; REF 2: at end DWDS) (n=8)

Regarding the selected micro-organisms, *Legionella* spp. and *Aeromonas* spp., the water quality was also stable in the three DWDSs, as shown in Figures 6 and 7.

Figure 6 shows that *Legionella* was already present in the incoming water and does not increase after passing the heat exchanger, neither in the system with the operational heat exchanger (system 1), nor in the system with the non-operational heat exchanger (system 2). Figure 7 shows comparable numbers for *Aeromonas* spp. in all three systems, irrespective of higher temperature after cold recovery.

In contrast, higher cell numbers and biological activity were detected in biofilm formed after cold recovery compared to the biofilm before cold recovery (2.5 times higher TCC and ATP, Figure 8). The different results found for bulk water and biofilm phases is probably due to the big difference in their exposure time to higher temperature (one minute for bulk water and six months for biofilm). The increased growth of biofilm after cold recovery may lead to a change in microbial community composition and structure. This preliminary research only lasted for a period of six months. On the longer term a changed microbial community composition may affect the microbial water quality in the bulk water phase.

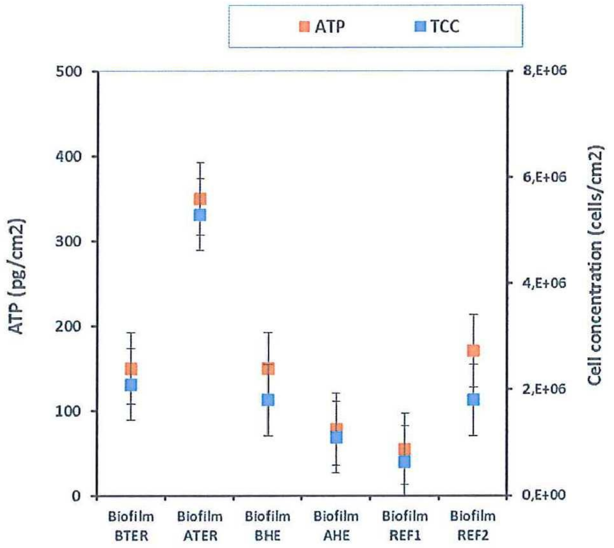

Figure 8. Biofilm development in DWDS 1 (BTER: before thermal energy recovery; ATER: after thermal energy recovery), DWDS 2 (BHE: before heat exchanger; AHE: after heat exchanger), DWDS 3 (REF1: at start of DWDS; REF 2: at end DWDS) and inside the operational heat exchanger in DWDS 1 (IHE) (n=1)

4 Conclusions

Thermal energy recovery from drinking water is applied at full scale and offers an alternative for the use of fossil fuel and thus contributes to the reduction of GHG emissions. Cold recovery, as applied in a specific case in Amsterdam, showed to have a positive business case: compared to a traditional system with cooling machines, TCO decreased from € 8.0 mln to € 5.4 mln. Preliminary research at laboratory scale showed that the microbial drinking water quality, measured by TCC, ATP, *Legionella* spp. and *Aeromonas* spp., was not affected by cold recovery. However, biofilm formation increased after cold recovery and requires further research to reveal the potential role of enhanced biofilm growth on microbiological water quality.

Acknowledgements

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