University of Banja Luka
Faculty of Mechanical Engineering

PROCEEDINGS

DEMI 2023

Banja Luka, Jun 2023

16TH INTERNATIONAL CONFERENCE ON ACCOMPLISHMENTS IN MECHANICAL AND INDUSTRIAL ENGINEERING

DEMI 2023

Supported by:

MINISTRY FOR SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT, HIGHER EDUCATION AND INFORMATION SOCIETY
OF THE REPUBLIC OF SRPSKA

Organizer and publisher:

FACULTY OF MECHANICAL ENGINEERING UNIVERSITY OF BANJA LUKA

Co-organizer:

FACULTY OF MECHANICAL ENGINEERING UNIVERSITY OF NIŠ, SERBIA

FACULTY OF MECHANICAL ENGINEERING UNIVERSITY OF PODGORICA, MONTENEGRO

FACULTY OF ENGINEERING HUNEDOARA
UNIVERSITY POLITEHNICA TIMIŞOARA, ROMANIA REYKJAVIK

UNIVERSITY, ICELAND

For publisher:

Full Prof. Aleksandar Milašinović, PhD

Editor of chief:

Full Prof. Petar Gvero, PhD

Executive editor:

Biljana Prochaska, PhD
Milivoj Stipanović, BsC

ORGANIZING COMMITTEE

Prof. Petar Gvero, PhD
Chairman of Organizing and Scientific Committee
Faculty of Mechanical Engineering, University of Banja Luka

Prof. Aleksandar Milašinović,
PhD Prof. Zorana Tanasić, PhD
Assoc. Prof. Stevo Borojević, PhD
Assoc. Prof. Goran Janjić, PhD
Assist. Prof. Dejan Branković, PhD
Prof. Uroš Karadžić, PhD
(Faculty of Mechanical Engineering, Podgorica)
Assoc. Prof. Dejan Mitrović, PhD
(Faculty of Mechanical Engineering, Niš)
Assoc. Prof. Sorin Ioan Deaconu, PhD
(Faculty of Engineering Hunedoara, Romania)
Assist. Prof. David C. Finger, PhD
School of Science and Engineering University of Reykjavik, Iceland
Goran Jotić, Senior Assistant, MSc
Saša Tešić, Assistant, MSc
Gordana Tošić, Assistant, MSc
Ivana Savković, Assistant, MSc
Dijana Đeorđić, Assistant, MSc
Biljana Prochaska, PhD
Sanja Maglov, MA+
Boro Marić, BA Law
Nedeljka Sladojević Putnik, BA Economics
Milivoj Stipanović, BSc
Zoran Grahovac, Assistant, MSc
Milisav Marković, Senior Assistant, MSc

SCIENTIFIC COMMITTEE

CONTENT

DEMI 2023
16th International Conference on Accomplishments in Mechanical and Industrial Engineering
Banja Luka
1–2 Jun 2023.
www.demi.mf.unibl.org

Wastewater as a new source of energy

V. Sustersic[a*], N. Aleksic[a], N. Rakic[a], M. Josijevic[a]

[a]*Faculty of Engineering, University of Kragujevac, Sestre Janic 6, 34000 Kragujevac, Serbia*

Abstract *Wastewater generated in municipalities and industries contains harmful pollutants which can have a negative impact on the environment. In developed countries, about 70-80% of municipal and industrial wastewater is collected and requires appropriate treatment and disposal. Treating wastewater takes a significant amount of energy – just under 1% of Europe's total energy consumption. However, wastewater contains significant energy potential. From the technical, economic and formal-legal side, they can be used in two ways: by using the thermal energy of wastewater and processing it to the level of technical water and its reuse. Also, sludge from wastewater treatment plant can be used in processes of anaerobic or co-digestion for production of biogas. This paper analyzes the possibility of using heat pumps and heat exchangers for wastewater heat recovery in buildings, as well as the possibility of using sludge in anaerobic digestion or co-digestion processes.*

Keywords *wastewater, co-digestion, heat recovery*

1. INTRODUCTION

The residential sector typically accounts for 30-40% of total energy consumption and carbon dioxide emissions in OECD countries [1]. In its effort to mitigate global warming, the European Union (EU) has set a target to reduce the carbon footprint of its buildings (Energy Performance of Buildings Directive (EPBD) [2]) which requires all new buildings to be nearly zero energy buildings from 2021. At the same time, the increase in the standard of living and the rapid development of the economy led to an increase in the daily production of household waste water.

Environmental protection policy aims to reduce pollution, and appropriate technologies in the field of wastewater heat recovery could contribute to this goal [3]. At the same time, EU Directive 2018/2001 recognized wastewater as a renewable source of heat [4], and the European Green Deal Investment Plan provides additional subsidies to member states for the implementation of waste heat reuse measures [5].

Wastewater from households, industry and the commercial sector contains considerable amounts of thermal energy after discharge into the sewage system [1]. From the technical, economic and formal-legal side, they can be used in two ways: using the thermal energy of wastewater and its reuse using heat pumps and heat exchangers, on the one hand (at the level of consumers, buildings, sewers and facilities), as well as using the sludge created in the wastewater treatment processes in the processes of anaerobic digestion and co-digestion to obtain biogas/energy, on the other hand.

Considering the plans [6] to build a wastewater treatment plants (WWTPs) in all settlements in Serbia, which are larger than 2,000 population equivalent (PE), by the year 2041, it can be adopted that it is profitable and acceptable for cities with over 50,000 PE to have anaerobic digestion and biogas production. In this sense, it can be accepted that in the medium term, these plants will represent a significant potential for the use and production of energy, including through heat pumps [7].

2. WASTEWATER HEAT RECOVERY

The heat energy in the wastewater could be recovered quite easily by using a heat exchanger placed in the wastewater flow and by the subsequent installation of a heat pump. In that scenario, wastewater heat recovery (WWHR) could take place at three different locations in the wastewater: (a) appliance level (usually at the shower), (b) building level (in the building), (c) sewer level (sewer network or a pumping station), and (d) WWTP level (in front of or behind the wastewater treatment plant) (Figure 1).

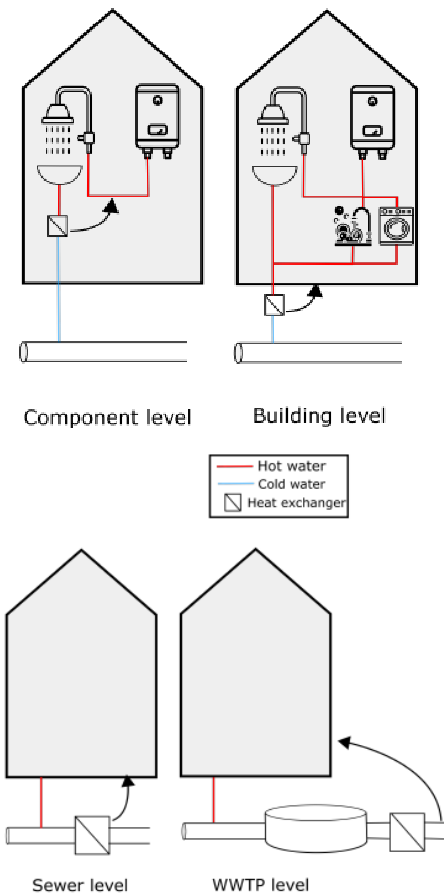


Fig. 1. Possibilities for heat energy recovery from wastewater [1]

The advantage of the last variant is high and continuous flows of (treated) wastewater, but this variant is often associated with unfavorable distances of energy supply, due to the remote location of the WWTP from the settlement. It should also be noted that heat extraction from wastewater can have an undesirable effect on temperature-sensitive treatment processes in WWTP [8].

In the first two cases, the situation is reversed, i.e. flows of (untreated) wastewater are discontinuous, but usually closer to potential consumers [8].

The implementation of heat pumps in centralized wastewater treatment systems has been known since the 80's of the last century, while more recently the possibilities for heat recovery in buildings have been considered, especially variants of heat recovery at the consumer itself, most often on showers [9].

The average temperature of grey water discharged from household is about 30°C. The installation of horizontal and vertical heat exchangers at the consumer in houses/ buildings ensures high efficiency because there is no time delay between the available waste heat and the need for heat energy (Figure 2). In this way, the need for heat storage is eliminated, thus avoiding losses [10].

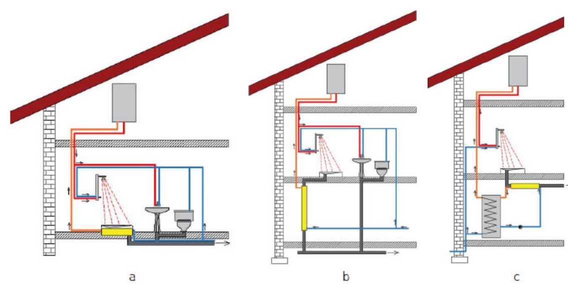


Fig. 2. Different types of drain water heat exchanger in household [11]

There are several places where hot water is used in buildings, including showers, bathtubs, washing machines, sinks, dishwashers, etc. The temperature, flow rate, frequency, and capacity of wastewater flow at a specific location depends on the consumer's water consumption pattern as well as seasonal and daily influence. These waters contain less pollutant and have higher temperature (Table 1).

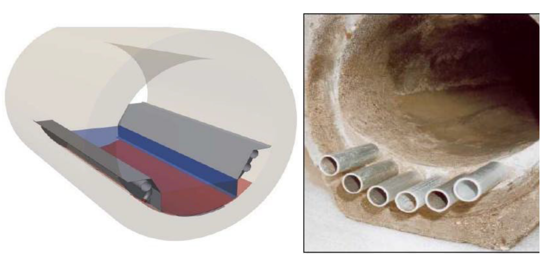
Table 1. DHW end-use temperature [12, 13]

End-use type	Temperature [^{0}C]
Hand washing	35-60
Washing and shaving	35

Dish washing	55-60
Showering	40-60
Bathing	40

At the level of residential buildings, due to the small volumes of wastewater flow and the high economic costs, heat pumps are not a viable option for heat recovery, but they are suitable for use in non-residential buildings. Facilities such as hotels, dormitories, hospitals are very interesting from the aspect of utilizing the heat of their wastewater using heat exchangers and/or heat pumps. For example, in the hotel facility "Tornik" on Zlatibor, a system for the preparation of sanitary water and central heating with water/water type heat pumps that use the energy of waste sanitary water was installed, and a cooling system was also provided in parallel [14].
Average water temperatures in sewer range from approximately 12°C in the winter, to over 20°C in the summer. But, the temperature of the sewage may drop significantly during cold weather or heavy rainfall, which can temporarily reduce the amount of recoverable heat. When it comes to installing heat exchangers in sewage systems, there are several ways (Figure 3):

- heat exchanger embedded in the sewage pipe,
- heat exchanger integrated in concrete wall of a sewage pipe and
- external heat exchanger placed above the ground [15].



a) b)

Fig. 3. Different design and types of the heat exchangers [16, 17]

The heat recovery from wastewater can be performed before WWTP from the raw wastewater (locations upstream in sewer network), or after the treatment in the WWTP (Figure 4). Which solution will be chosen depends on specific conditions, but the rule applies that the further we move away from households, the temperature drops, and the flow increases. On the other hand, the problem of negative impact on the WWTP performance arises as the temperature drops, because the purification efficiency depends on the inlet temperature [18].

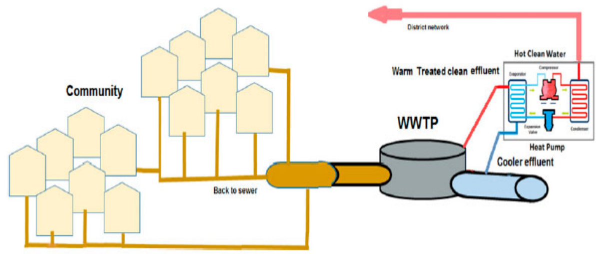


Fig. 4. Possibilities for heat energy recovery from wastewater treatment plant after WWTP [18]

Examples of application of heat pumps for heat recovery from WWTP can be found in Switzerland, Russia, Croatia and Scandinavia. It can be noted that there are significant variations in the coefficient of performance of heat pumps (COP) installed at WWTPs around the world [19]. For example, COP of heat pumps that are installed at WWTPs is 3, unlike those that are installed in buildings which is 7. The difference in temperature results in a difference in the COP of heat pumps on WWTP and buildings [20].

2.1 Legal frameworks

Numerous authors have identified wastewater as a significant source of heat for heating buildings. But, in general, there are no regulatory restrictions for the supply of waste heat into district heating (DH) networks, since virtually all waste heat supply situations are regulated using bi-lateral contracts between the DH network operator/utility and the company "owning" the waste heat [21]. In order to encourage wastewater heat recovery, governments can introduce wastewater heat recovery in their respective building codes and guidelines aimed at improving energy efficiency and reducing energy consumption and emissions. For example, in Germany, the Committee for Industrial Standards was established in 2021 to standardize the different methods used in measurements on wastewater heat recovery devices into a uniform performance and hygiene test procedure. Also, the EU regulation 812/2013 (Energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device) is getting revised in 2022 to introduce wastewater heat recovery in combination with water heaters to improve their EU energy label [22].

3. BIOGAS RECOVERY BY ANAEROBIC AND CO-DIGESTION

The application of sewage sludge obtained during different wastewater treatments fits into the objectives of the circular economy [21]. Sewage sludge is characterized by a high concentration of organic and nutrient substances, heavy metals and pathogens. Therefore, it is necessary to apply the treatment before energy valorization or final disposal. Wastewater treatment is of vital importance for environmental protection, but it is also an energy-intensive activity. Municipal wastewater treatment accounts for about 3% of global electricity consumption and 5% of global greenhouse gas emissions [23].

On the other hand, waste management, recycling, mitigating climate impacts and reducing GHG emissions represent the main goals of numerous political agendas, due to the increase in the population, increased demand for energy and due to the increase in the amount of waste. Taking into account the negative environmental impacts of landfilling, burning or composting waste, anaerobic digestion represents an economical technology for the production of renewable energy sources, as well as for the treatment of waste and/or sewage sludge containing a high percentage of moisture and energy-rich materials.

During digestion, anaerobic microbes convert different types of biomass and organic waste into biogas (60%-70% methane, 30%-40% carbon dioxide and traces of other gases such as hydrogen and hydrogen sulfide), leaving a nutrient-rich residue, which can be used for tillage use.

Anaerobic co-digestion represents the simultaneous digestion of a homogeneous mixture of two or more substrates of different organic fractions with different origins and physico-chemical compositions, in order to make the most of the complementary characteristics of their composition. It shows better process efficiency than mono-digestion, providing complementary advantages such as better biogas yield, wider availability of nutrients, lower substrate volume, substrate variability, dilution of toxicity, synergism, etc. [24].

Removing food waste from municipal waste, space can be saved for disposal of inert waste materials with a significantly lower impact on the environment during the operation of the landfill and after its closure. Food waste can come from food preparation, or it can be fruit and vegetable waste. It is mainly characterized as easily degradable, with high moisture content, low pH and highly soluble organic ingredients, which can give a higher energy content per dry mass, i.e. food waste is rich in energy content that can significantly improve biogas yield [25].

Although anaerobic co-digestion is a relatively well-known and widely applied technology in the treatment of wastewater, sewage sludge and manure, the adoption of this technology for food waste management still faces several technical, economic and social challenges, such as the accumulation of volatile fatty acids and process instability, foaming, low buffering capacity, and high cost of transportation and processing.

An ideal co-digestion anaerobic process must include: characterization of food residues and waste production rate, facilities for the collection and separation of biodegradable waste from municipal solid waste, optimal technology for pre-treatment of biodegradable waste before the co-digestion process, regulated control and reactor construction for the desired manipulation of metabolic reaction, improving the quality of biogas in order to reduce the costs of subsequent purification and an efficient plan for using digestate for composting, in order to achieve optimal working conditions and obtain the highest possible yield of biogas (from 10-over 50%) [26].

4. CONCLUSION

Today, about 35% of the EU's buildings are over 50 years old and almost 75% of the building stock is energy inefficient. Wastewater heat recovery is currently not yet officially recognized and therefore its application does not bring constructors any legal improvements in the energy efficiency, despite the obvious energy savings. This paper aims to provide an overview of wastewater heat recovery and the possibility of using sludge in anaerobic digestion or co-digestion processes. The performance of these systems varies depending on the type of energy users, equipment and system design, as well as their own maintenance.

Instead of the energy consumption that is a common feature of aerobic process, anaerobic digestion is accompanied by the production of biogas that can be used as an energy source. Unlike landfilling, incineration or composting, anaerobic digestion or co-digestion is the only waste treatment method that meets the sustainability requirements by restoring the waste's energy content in the form of the methane and nutrient content. Therefore, co-digestion of municipal organic waste in combination with municipal sludge not only enables the treatment facilities to be energy neutral, but also reduces the costs of municipal organic waste management.

REFERENCES

[1] Nagpal, H., Spriet, J., Mutali K. M., McNabola, A. (2021) Heat Recovery from Wastewater—A Review of Available Resource, *Water*, 13, 1274. https://doi.org/10.3390/w13091274

[2] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

[3] Hadengue, B., Morgenroth, E., Larsen A.T. (2022) Screening innovative technologies for energy-efficient domestic hot water systems, *Journal of Environmental Management,* 320 115713, https://doi.org/10.1016/j.jenvman.2022.115713

[4] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Off. J. Eur. Union 2018, 5, 82–209.7

[5] Sustainable Europe Investment Plan European Green Deal Investment Plan; Technical Report; European Commision: Brussels, Belgium, (2020). Available online: https://eurlex.europa.eu/legalcontent/EN/TXT/?uri=CELEX%3A52020DC0021 (accessed on 29 March 2023).

[6] WATER MANAGEMENT STRATEGY IN THE TERRITORY OF THE REPUBLIC OF SERBIA UNTIL 2034 ("Official Gazette of RS", No. 3/2017) (in Serbian)

[7] Ivezić, D., Živković, M., Madžarević, A., Pavlović, B. (2022) Possibilities for Utilization of Waste Heat from Wastewater Treatment Plants by Heat Pumps, *Energy, economy, ecology*, XXIII, no 1, p. 162-166

[8] Huber, F., Neugebauer, G., Ertl, T., Kretschmer, F. (2020) Suitability Pre-Assessment of in-Sewer Heat Recovery Sites Combining Energy and Wastewater Perspectives, *Energies*, 13, 6680. https://doi.org/10.3390/en13246680

[9] Hadengue, B., Joshi, P., Figueroa, A., Larsen, A. T., Blumensaat, F. (2021) In-building heat recovery mitigates adverse temperature effects on biological wastewater treatment: A network-scale analysis of thermal-hydraulics in sewers, *Water Research*, 204, 117552. https://doi.org/10.1016/j.watres.2021.117552

[10] Davila, A.R., Cejudo, M.C.E., Stoughton, K. (2020) *Domestic Hot Water Temperature Maintenance Technology Review*, Technical Report PNNL-SA-156938 United States. https://doi.org/10.2172/1813897

[11] Vaičiūnas, J., Geležiūnas, V., Valančius, R., Jurelionis, A., Ždankus, T. (2016) Analysis of Drain Water Heat Exchangers System in Wellness Center, *Journal of Sustainable Architecture and Civil Engineering,* vol. 17, no 4. p. 15-23 http://dx.doi.org/10.5755/j01.sace.17.4.16294

[12] Bertrand, A., Mastruccia, A., Schülerb, N., Aggounec, R., Maréchа, F. (2017) Modelling of Domestic Hot Water End-Uses for Integrated Urban Thermal Energy Assessment and Optimisation, *Applied Energy*, vol. 186(P2), p.152-166

[13] Davila, A.R., Cejudo M.C.E., Stoughton, K. (2021) *Domestic Hot Water Temperature Maintenance Technology Review*, Technical Report PNNL-SA-156938 United States. https://doi.org/10.2172/1813897

[14] Tornikova energana https://www.inzenjer.net/projekti/tornikova-energana/ (accessed on 29 March 2023).

[15] Oesterholt, F., Hofman J. (2015) *Feasibility of small scale heat recovery from sewers*, report, BTO 2015.208(s), Water Research Institute

[16] Podobeková, V., Peráčková, J. (2013) Heat exchangers in sewage pipes, *The Holistic Approach to Environment,* vol. 4, no. 2, p. 91-96

[17] Niewitecka, K. (2018) Possibilities of heat energy recovery from greywater systems, E3S Web of Conferences 30, *Water, Wastewater and Energy in Smart Cities,* 03003 https://doi.org/10.1051/e3sconf/2018300303

[18] Ali, S.F., Gillich, A. (2021) Opportunities to decarbonize heat in the UK using Urban Wastewater Heat Recovery, *Building Services Engineering Research and Technology,* Vol. 0(0) p.1–18 https://doi.org/10.1177/01436244211034739

[19] Golzar, F., Silveira, S. (2021) Impact of wastewater heat recovery in buildings on the performance of centralized energy recovery – A case study of Stockholm, *Applied Energy*, 297 117141. https://doi.org/10.1016/j.apenergy.2021.117141

[20] Meggers F, Leibundgut H. (2011) The potential of wastewater heat and exergy: Decentralized high-temperature recovery with a heat pump. *Energy Building*; 43: p. 879–86. https://doi.org/10.1016/j.enbuild.2010.12.008

[21] Zarei, M. (2020) Wastewater resources management for energy recovery from circular economy perspective, *Water-Energy Nexus*, 3, p. 170–185. https://doi.org/10.1016/j.wen.2020.11.001

[22] Sevela, P., Frenger, J., Schnieders, J., Pfluger, R. (2022) The potential of Waste Water Heat Recovery Systems in reducing the energy demand for water heating in the EU in a cost-efficient way, CLIMA, the 14th REHVA HVAC World Congress, 22-25 May, Rotterdam, The Netherlands https://doi.org/10.34641/clima.2022.439

[23] Zhou, X., Yang, F., Yang, F., Feng, D., Pan, T., Liao, H. (2022) Analyzing greenhouse gas emissions from municipal wastewater treatment plants using pollutants parameter normalizing method: case study of Beijing, *Journal of Cleaner Production*, vol 376, 134093 https://doi.org/10.1016/j.jclepro.2022.134093

[24] Mata-Alvarez J, Macé S, Llabrés P (2000) Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. Bioresource Technology 74:3–16. https://doi.org/10.1016/S09608524(00)0003-7

[25] Bong, C.P.C., Lim, L.Y., Lee, C.T., Klemeš, J.J., Ho, C.S., Ho, W.S. (2018) The characterisation and treatment of food waste for improvement of biogas production during anaerobic digestion – A review, *Journal of Cleaner Production*, vol. 172, p. 1545-1558, https://doi.org/10.1016/j.jclepro.2017.10.199

[26] Morales-Polo, C., Cledera-Castro, M., Soria, B. Y.M. (2018) Reviewing the Anaerobic Digestion of Food Waste: From Waste Generation and Anaerobic Process to Its Perspectives, *Applied Sciences*, 8, 1804; https://doi:10.3390/app8101804