David Tomás Sánchez Martínez
Lourdes García Rodríguez
(coordinadores)

Proceedings of the 7th International Seminar on
ORC
Power Systems

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(coordinadores)

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PERFORMANCE OF ORGANIC RANKINE CYCLE SYSTEM IN COMBINATION WITH RESIDUAL MUNICIPAL SOLID WASTE GASIFICATION: A SIMULATION ANALYSIS

Luca Cioccolanti[1,*], Giovanni Biancini[1], Ramin Moradi[2], Luca Del Zotto[1], Matteo Moglie[1]

[1] *University eCampus, Research Center for Energy, Environment and Landscape, Via Isimbardi 10, 22060 – Novedrate (CO) Italy*

[2] *Department of Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow, UK*

*Corresponding Author: luca.cioccolanti@uniecampus.it

ABSTRACT

Despite recycling is largely adopted in Europe, the amount of disposed municipal solid waste (MSW) from mechanical-biological treatment is increasing. At the same time, more environmentally friendly waste-to-energy (WtE) solutions are needed to promote sustainable management of residual MSW (RMSW) compared to incineration, which is the most common process to valorise MSW.

Among the waste-to-energy solutions, gasification is considered a promising option and nowadays attention is paid to the use of residual MSW as feedstock. In addition, organic Rankine cycle (ORC) systems are one of the most suitable technologies to produce electricity from low-grade energy sources such as that obtained from the gasification of residual MSW.

Therefore, in this work, a RMSW air gasifier in combination with an ORC unit are investigated using Aspen Plus for combined heat and power (CHP) applications. The simulation analysis is performed considering the potential syngas production from RMSW of a real composting facility in Italy. Three different working fluids are investigated to assess the energy performance of the integrated system for CHP production in district heating networks. The analysis reports an overall conversion efficiency of the integrated system in the range 38.4% - 48.5% and a maximum power production of the ORC unit of 2.14 $\mathrm{MW_e}$ with the use of toluene. Therefore, the present study shows that the gasification of RMSW and the exploitation of its energy content in an ORC system is a viable option to reduce the environmental burden in compositing facilities by extending the lifetime of the landfills.

1 INTRODUCTION

The sustainable management of municipal solid waste (MSW) is one of the pillars of the circular economy paradigm and a key action towards a more secure and competitive energy system in the EU. Despite recycling is considered the best solution in waste management, in some cases other methods are adopted for the valorisation of organic fraction of MSW and residual MSW (RMSW). The RMSW is mainly composed of a heterogeneous mixture of unrecycled materials that can be valorised by cold processes like mechanical-biological treatment (MBT) or consolidated waste incineration. As regards the latter, there are yet many operational plants in combination with organic Rankine cycle (ORC) units and it is also largely investigated in the literature. For example, Tozglu et al. (Tozlu et al., 2021) investigated different scenarios for the valorisation of MSW incineration for power production and district heating potential in Turkey finding that gas turbine power plants can increase the power generation capacity of MSW plants for each province by about 20%. Ustaoglu et al. (Ustaoglu et al., 2022), instead, conducted energy and exergy analysis of an ORC cogeneration system powered by MSW incineration for different working fluids finding that R141b performs the best among the selected fluids. However, incineration of MSW comes at the cost of high environmental impact which made other waste-to-energy (WtE) methods of interest. Indeed, MSW can be valorised also by pyrolysis and gasification technologies (Ruiz et al., 2013), which have lower environmental impacts compared to incineration (Moradi et al., 2023). In the pyrolysis process, the feed material is thermally decomposed into oil, gas, and solid residues through a lean oxidation process while in the gasification the organic and carbon content of the input material process is converted into carbon monoxide, methane, hydrogen, and carbon dioxide with a controlled amount of the oxidant agent at high temperatures (>700°C).

The gasification of biomass feedstocks has been extensively studied in the literature, while co-gasification of mixture of biomass and other materials has not been explored much. For example, Mastellone et al. (Mastellone et al., 2010) investigated a more diverse composition represented by different mixtures of coal, waste plastic, and wood in a bubbling fluidized bed reactor demonstrating the feasibility of gasification of heterogeneous materials. Win et al. (Win et al., 2019) used an air fluidized bed gasifier for syngas production from residual paper, plastic, and wood pellets obtaining a low heating value (LHV) of the produced syngas in the range of 3.4-5.9 MJ/Nm^3 with varying equivalence ratio (ER) and feedstock type. In this context, residue-derived fuel (RDF) which is a pellet-like secondary fuel obtained downstream MBT process is attracting attention thus reducing its landfilling and the environmental burden of its disposal.

However, while the syngas produced from wood biomass gasification can be straightforwardly used in internal combustion engines (ICEs) and gas turbines, the exploitation of that from plastic gasification is more challenging. The high tar content and low ash melting point of the latter, indeed, may limit its use in external combustion power cycles. Among these power plants, ORC systems are one of the most efficient and competitive technologies and prove to perform even better than traditional Rankine cycles (Vankeirsbilck et al., 2011) for this kind of application. In turn, the chemical stability of the working fluids in ORCs usually limits the maximum operating temperature to around 300°C as also reported by Vescovo and Spagnoli (Vescovo & Spagnoli, 2017). For this reason, there are several works in literature (Li et al., 2018; Moradi et al., 2020) dealing with the integration of ORC systems as bottoming units in combined cooling heating and power or combined heating and power plants based on biomass gasification; yet addressing the use of ORC systems in combination with RMSW gasification is relatively scarce. Nevertheless, recent EU directives are supporting more environmentally friendly alternatives to RMSW incineration and therefore in this work the direct combination of RMSW gasification with ORC power plant is investigated. In particular, the general model of a fluidized bed air gasifier developed in a recent paper by the authors (Biancini et al., 2023) to estimate the syngas characteristics from RMSW of a real composting facility is here integrated with the model of a subcritical ORC system. The final aim is to estimate the RMSW overall potential for the provision of combined heat and power (CHP) in district networks in the perspective of more efficient and environmentally friendly management of the RMSW from composting facilities.

2 MATERIALS & METHODS

In this section, the composting facility under investigation is initially described and then the integrated model of the fluidized bed air gasifier and the ORC system is presented.

2.1 The compositing facility under investigation

The composting facility operates in the centre of Italy, and it mainly consists of: i) a section for the treatment of the organic fraction of the MSW which includes the anaerobic digesters and a 700 kW$_e$/400 kW$_t$ CHP unit; ii) a MBT unit for the shredding, sorting, and recovery of the RMSW produced in the nearby municipalities; iii) a sanitary landfill for the disposal of the RMSW, and iv) a biogas-fuelled 250 kW$_e$ ICE unit. It is worth noting that the CHP unit above works at part load conditions as a consequence of the biogas production from the digesters and that almost all the electricity produced is self-consumed in the air treatment process which represents the most energy-intensive process in the site. Further details about the composting facility can be found in Biancini et al. (Biancini et al., 2022).

In total, almost 80 ktons/year of RMSW are landfilled and about 20 ktons/year of residues are locally produced at the MBT unit. The latter is mainly composed of residual plastic and paper with an overall LHV of about 21 MJ/kg. Since during the operation this composition may be subjected to changes, its variation is accounted in this work by considering data from the literature. In particular, the following two additional compositions are assumed: plastic 68% + paper 32% (defined as "S2") and plastic 54% + paper 46% (defined as "S6") according to Bourtsalas and Themelis ((Thanos) Bourtsalas & Themelis, 2022). These mixtures bring to the minimum and maximum syngas LHV of (4526 kJ/Nm^3, with ER=0.33) and (6585 kJ/Nm^3, with ER=0.25) respectively. At the same time, the volumetric flow rate of the obtained syngas is higher in S2 than in S6 being equal to 6788 Nm^3/h and 4290 Nm^3/h respectively. Further details on the compositions and the obtained syngas characteristics are presented in (Biancini et al., 2023).

Therefore, in the present study the configuration of the real composting facility is modified by accounting for the RMSW gasification section and the ORC power generation unit downstream of the gasifier as reported in Figure 1. In particular, the syngas is burnt in an external combustion chamber because of its high tar content and the thermal energy of the flue gas is transferred to the ORC unit using diathermic oil (Therminol VP-1). The proposed scheme of the power cycle is similar to those commercially provided by Turboden and Ormat (Tartière & Astolfi, 2017).

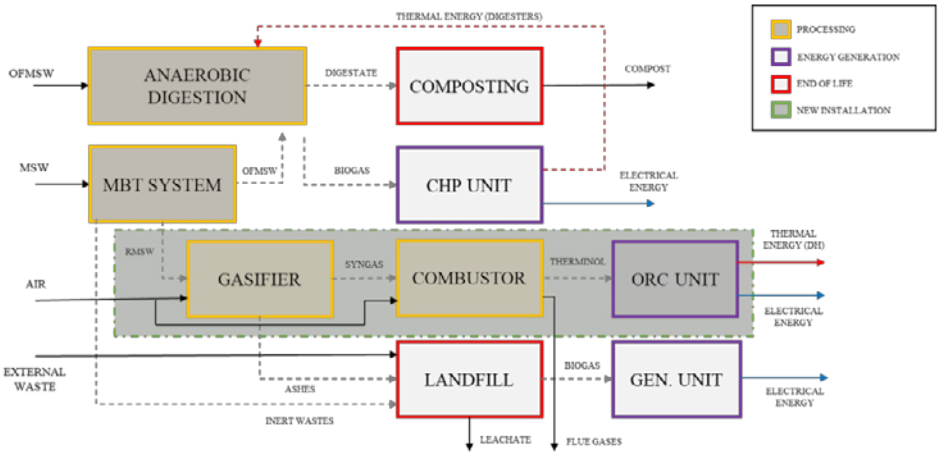


Figure 1: Conceptual scheme of the waste treatment facility. The green colour highlights the proposed gasifier + ORC section integrated into the current composting facility.

Hence, concerning the current situation, the proposed configuration would reduce the load on the landfill by limiting the disposal to inert materials and ashes only while increasing the energy valorisation of the MSW. Regarding the working fluids, toluene performs well among cycloalkanes, whereas super-dry fluids like MM and MDM are optimal for regenerative setups (Zhang & Li, 2023). Therefore, these fluids have been selected for the subsequent thermodynamic analyses.

2.2 The model

The thermochemical model of the fluidized bed gasifier was derived from a previous model of a fluidized bed steam gasifier developed by some of the authors of the present paper (Moradi et al., 2020) and adapted to the use of air as the gasifying agent and different feedstock compositions in (Biancini et al., 2023). In the latter, the model was previously validated against experimental data reported in the literature and then its use was extended to RMSW input material. The entire thermochemical process is divided into four main blocks according to an updraft configuration: i) the heater block for the biomass drying; ii) the RYIELD block to emulate the fast pyrolysis process of the input material; iii) the RGIBBS reactor which represents the combustion process providing heat; iv) the RGIBBS reactor to model the gasification process. Further details about the thermochemical model are presented in (Biancini et al., 2023). Then, the produced syngas is burned in an external combustion chamber and the energy content of the exhausts indirectly exploited by the bottoming ORC unit using a diathermic oil loop. A regenerative ORC cycle is considered as shown in Figure 2 to increase the conversion efficiency in accordance with Braimakis and Karellas (Braimakis & Karellas, 2018). The air mass flow rate, $\dot{m}_{air}$ [kg/h], for the syngas combustion, is evaluated from the stoichiometric combustion of the C_nH_mO compounds and considering a certain excess of air, e, to assure its complete combustion. Hence, the air mass flow rate is calculated according to Equations (1-4):

$$\dot{m}_{C_nH_m,st} = \dot{m}_{C_nH_m} \times 32\frac{(n+m/4)}{(12n+m)} \tag{1}$$

$$\dot{m}_{CO,st} = \dot{m}_{CO} \times \frac{16}{12+26} = 0.571 \times \dot{m}_{CO} \tag{2}$$

$$\dot{m}_{air,st} = \dot{m}_{C_nH_m,st} + \sum \dot{m}_{C_nH_m,st} \tag{3}$$

$$\dot{m}_{air} = \dot{m}_{air,st} \times (1+e) \tag{4}$$

where $\dot{m}_{air,st}$ is the stoichiometric air mass flow rate [kg/h], $\dot{m}_{C_nH_m,st}$ and $\dot{m}_{CO,st}$ are the stoichiometric air mass flow rates [kg/h] for the complete combustion of both the hydrocarbon gases C_nH_m and CO. The diathermic oil recovers the heat of the exhausts in the heat exchanger HX1 and transfers it to the ORC evaporator heat exchanger HX2. The regenerator is the heat exchanger HX3 and HX4 is the ORC condenser which is water-cooled. The performance of the heat exchangers is estimated using the ε-NTU method after a preliminary geometry characterization of the heat exchangers (Cavallini, 2017): cross-flow type heat exchangers with unmixed gas sides for HX1 and HX3, Shell & Tube (ST) with two shell passages for HX2, and single shell passage ST for HX4.

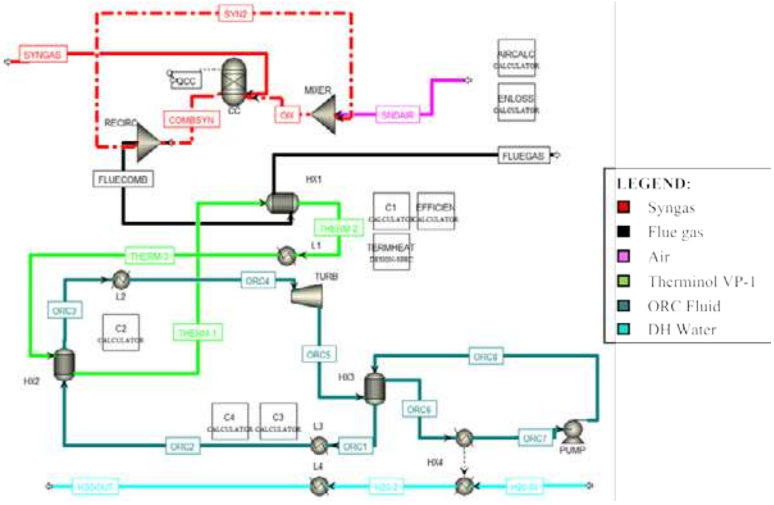


Figure 2: The integrated plant layout of the model developed in Aspen Plus.

The characteristics of the thermodynamical model are summarised in the following:

- The Peng-Robinson with Boston-Mathias modification is used as the equation of state for the calculation of the properties of the fluids. Water properties (light blue in Figure 2) are defined according to IAPWS-95 (Industrial Formulation for the Thermodynamic Properties of Water and Steam).
- The combustor (RGIBBS block) works with a fixed flue gas recirculation ratio of 20% and excess air of 150%. The combustion efficiency is considered 95%. Flue gas temperature after HX1 is fixed to 260°C since lower temperatures may lead to the formation of corrosive substances on the chimney wall, while higher ones may result in failures of the gas cleaning equipment and lower energy recovery rates. Inlet conditions of diathermic oil at HX1 are 180 °C and 10 bar.
- The NTU of each heat exchanger is in the range of $0.2<NTU<5$ to avoid unfeasible area design. In such conditions, ε is lower than 95%.
- Thermal losses are accounted for in heat exchangers as follows: 10% for HX1 and HX4, 5% for HX2 and HX3. Such heat losses are modelled using 4 additional heat exchangers (L1 to L4) that have a negative thermal load defined by four calculator blocks (C1 to C4)
- The isentropic efficiency of the three-stage turbine is evaluated through the mathematical correlation proposed by Macchi and Astolfi (Macchi & Astolfi, 2017) for multistage axial turbines. The maximum allowable values for Size Parameter (SP) and Volume Ratio (VR) are

1 and 400 respectively. On the contrary, a constant isentropic efficiency of 75% is assumed for the pump due to its limited influence on the cycle performance. The electrical and mechanical efficiencies are assumed to be 0.97 and 0.95 respectively for the turbine and pump.

- The district heating (DH) network is a third-fourth generation (Yuan et al., 2021). This means that the hot-side water temperatures (T_{DH}) range from 55°C to 95°C with a 20°C step. At the condenser, the temperature difference at the cold side is considered fixed at 30°C, and a sub-cooling degree (ΔT_{SC}) of 5 °C is assumed.
- The maximum pressure of the ORC working fluid is assumed 80% of its critical pressure, and a superheating degree of the working fluid (ΔT_{SH}) of 10°C is assumed at the HX2 outlet.
- The minimum temperature difference of the hot fluid at the recuperator (ΔT_{REG}) is assumed 30°C.

3 RESULTS AND DISCUSSIONS

The quality of the RMSW in terms of its composition, and the ER in the fluidized bed gasifier strongly affects the thermal power input to the bottoming ORC system. Due to the variability of the RMSW, such input cannot be fixed and easily defined at priori. Nevertheless, for the sake of this study three different RMSW compositions and gasifier operating conditions are considered: i) the present composition of the RMSW provided by the composting facility under investigation (Baseline scenario) with ER = 0.3; ii) the S2 composition with ER = 0.33; and iii) the S6 composition with ER = 0.25. Further details of the selected RMSW properties can be found in the authors' previous work (Biancini et al., 2023)

3.1 Energy production from baseline RMSW

The most significant properties of the identified working fluids for the ORC system are reported in Table 1.

Table 1: The properties of the working fluids considered for the ORC system (Lai et al., 2011; Vescovo & Spagnoli, 2017).

Working Fluid	Chemical Formula	Molecular Weight [g/mol]	T_{crit} [°C]	P_{crit} [bar]	T_{min} [°C]	T_{max} [°C]
Toluene	C_7H_8	92.14	318.6	41.1	85	350
MM	$C_6H_{18}OSi_2$	162.38	245.9	19.2	30	290
MDM	$C_8H_{24}O_2Si_3$	236.53	291.3	14.6	80	290

Figure 3 shows the T-s diagrams of the three working fluids and their maximum and minimum operating pressures considering the heat input from the combustion of the syngas from the gasification of the RMSW in the Baseline scenario.

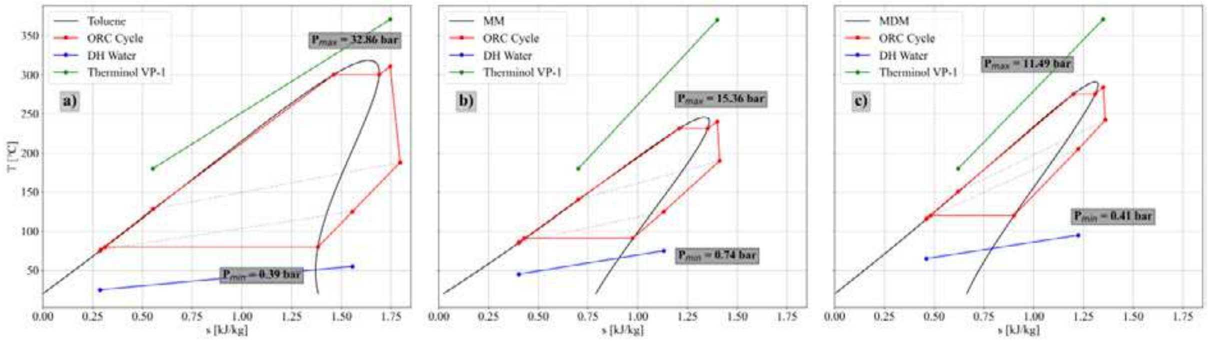


Figure 3: T-s diagram of the selected working fluids: a) toluene; b) MM; and c) MDM.

For a given heat input, the operating conditions of the fluids are strongly influenced by the saturation curves of the fluids. Being fixed the inlet and outlet conditions of the heating and cooling fluids, namely oil and water respectively, and in accordance with the assumptions described above, the model calculates the working fluid mass flow rate iteratively.

MDM has the lowest condensing pressure for a given temperature among the fluids under investigation. At a condensing temperature of 120° C, the corresponding pressure is 0.41 bar. As a consequence, the electric efficiency of the cycle is not affected by the supplying temperature of the hot fluid in the DH network since it is not recommended to operate at lower condensing temperatures. In the case of toluene, instead, the condensing temperature can be reduced to 80°C thus taking benefit of lower hot fluid temperatures in the DH network. Therefore, the minimum T_{DH} of 55°C is considered in the case of toluene. Eventually, MM is in between these two cases with a minimum condensing temperature of 90°C and a corresponding minimum T_{DH} of 75°C. Based on the thermodynamic conditions described before, the model calculates the mass flow rates of the working fluids (34.706 kg/h for Toluene, 63.639 kg/h for MM, and 57.964 kg/h for MDM) resulting in the power generation and conversion efficiencies, with respect to the evaporator (HX2), flue gas (HX1) and gasifier thermal power input, reported in Table 2.

Table 2: Performance of ORC system for the Baseline scenario.

Working Fluid	**Q_{cond} [MW]**	**W_{turb} [MW]**	**HX2**		**HX1**		**Q_{GASIF} = 13.5 MW**	
			η_t [%]	**η_{el} [%]**	**η_t [%]**	**η_{el} [%]**	**η_t [%]**	**η_{el} [%]**
Toluene	3.92	1.40	63.4	21.7	57.1	19.6	29.1	10.0
MM	4.26	0.97	69.2	15.0	62.3	13.5	31.6	6.8
MDM	4.55	0.74	73.5	11.3	66.2	10.2	33.7	5.2

The highest power production is obtained with toluene whereas the highest thermal output is achieved with MDM. From the conversion efficiencies point of view, toluene has the highest electrical and overall conversion efficiencies of 10% and 39.1% (with respect to the LHV of the RMSW), followed by MDM and MM having a total conversion efficiency of 38.4% and 38.9% respectively.

3.2 Energy production from S2 and S6

The performance of the ORC system in S2 and S6 scenarios is reported in Table 3 for all the considered working fluids. The produced electrical and thermal powers are significantly higher for S2 compared to S6 due to the greater syngas yield achieved from the former (mass flow rate of 6800 Nm^3/h and 4300 Nm^3/h for S2 and S6 respectively) despite the lower LHV (4500 kJ/Nm^3 and 6600 kJ/Nm^3 for S2 and S6 respectively). Figure 4 reports the T-s diagrams of the three working fluids for these scenarios.

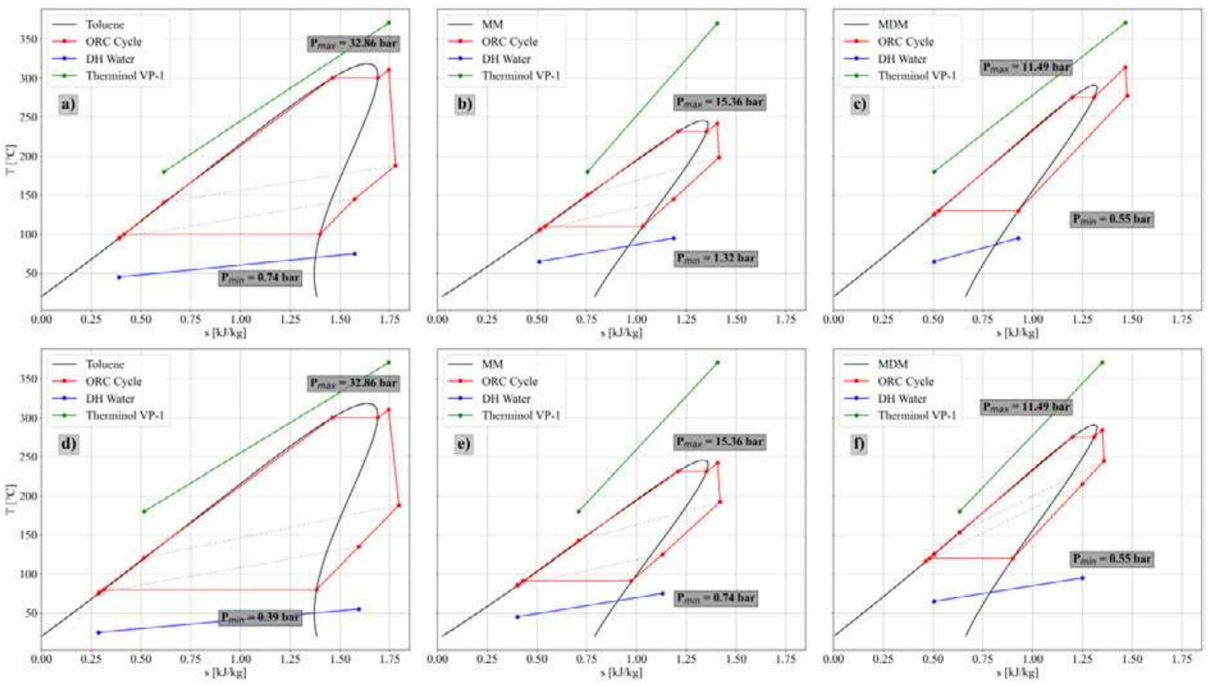


Figure 4: T-s diagram of the three working fluids for S2 (a,b,c) and S6 (d,e,f) scenarios.

Comparing T-s diagrams in Figure 3 with those in Figure 4, it can be noted that the ORC using toluene is not subjected to significant changes in its operation with RMSW composition. On the contrary, regeneration cannot be applied in S2 scenario due to SP > 1 or unfeasible heat exchangers NTU when MDM is considered as depicted in Figure 4c. In this case, higher condensation pressures and lower ΔT_{RIG} at HX3 are required to counterbalance these results. Nevertheless, the SP of MDM is inevitably higher due to the small enthalpy difference in the turbine despite an incremented turbine inlet temperature of 315°C and a superheating degree of 40°C which is far from the optimum operating conditions.
Table 3 reports the overall performance of the ORC power unit for S2 and S6 scenarios.

Table 3: Performance of ORC system in S2 and S6 scenarios with different working fluids.

Working Fluid	Q_{cond} [MW]	W_{turb} [MW]	HX2		HX1		Q_{GASIF_S2} = 18.6 MW Q_{GASIF_S6} = 13.8 MW	
			η_t [%]	η_{el} [%]	η_t [%]	η_{el} [%]	η_t [%]	η_{el} [%]
Toluene S2	6.72	2.14	65.3	19.9	58.8	17.9	36.2	11.0
Toluene S6	5.03	1.73	64.1	21.1	57.7	19.0	36.5	12.0
MM S2	7.34	1.38	71.7	12.6	64.5	11.3	39.5	6.9
MM S6	5.40	1.23	69.2	15.0	62.3	13.5	39.1	8.5
MDM S2	7.94	0.94	77.0	8.7	69.3	7.8	42.7	4.8
MDM S6	5.84	0.86	74.6	10.4	67.1	9.4	42.4	5.9

Like the Baseline scenario, the use of toluene leads to the highest electrical efficiency. The thermal recovery, instead, is enhanced with the siloxane fluids i.e. MM and MDM. Therefore, toluene is the best to obtain the maximum power output or overall conversion efficiencies, while siloxanes are suggested for DH application.

3.3 Sensitivity analysis with fluid temperatures in DH network

The analysis in sub-section 3.1 reveals that among the considered working fluids, only toluene can change its condensing pressure in accordance with the entire span of fluid temperatures in the DH network. Hence, a sensitivity analysis with fluid temperatures in DH network is conducted to assess the variation of ORC performance using toluene as the working fluid. For the sake of this analysis, the discharge pressure of the ORC turbine is iteratively varied to reach a fixed pinch point of 10 °C at HX4 whereas the outlet temperature of the hot fluid after regeneration (HX3) is the minimum one fulfilling the NTU and SP constraints above. The results of this sensitivity analysis are reported in Table 4.

Table 4: Performance of ORC system using toluene with fluid temperature in DH network.

	Discharge Pressure [bar]	**Q_{cond} [MW]**	**W_{turb} [MW]**	**HX2**		**HX1**		**Q_{GASIF} = 13.5 MW** **Q_{GASIF_S2} = 18.6 MW** **Q_{GASIF_S6} = 13.8 MW**	
				η_t [%]	**η_{el} [%]**	**η_t [%]**	**η_{el} [%]**	**η_t [%]**	**η_{el} [%]**
Base 55°C	0.28	3.92	1.36	63.3	21.9	57.0	19.7	29.0	10.0
Base 75°C	0.40	3.94	1.33	63.7	21.5	57.3	19.3	29.2	9.8
Base 95°C	0.91	4.00	1.26	64.8	20.3	58.3	18.3	29.7	9.3
S2 55°C	0.57	6.63	2.14	64.3	20.8	57.9	18.7	35.6	11.5
S2 75°C	0.58	6.60	2.14	64.1	20.8	57.7	18.7	35.5	11.5
S2 95°C	0.91	6.69	2.07	65.0	20.1	58.5	18.1	36.0	11.1
S6 55°C	0.34	4.92	1.77	62.7	22.6	56.4	20.3	35.6	12.8
S6 75°C	0.40	5.01	1.68	63.8	21.4	57.4	19.2	36.3	12.2
S6 95°C	0.90	5.09	1.59	64.9	20.2	58.4	18.2	36.9	11.5

As expected, the electric efficiency increases when the turbine backpressure is decreased while the thermal efficiency has an opposite trend although with minor variations. However, in the case of S2 scenario the turbine power remains the same for hot fluid temperatures in DH network of 55°C and 75°C due to the limits of the working fluid for the fixed constraints. Independently from fluid temperature, the overall efficiency referred to the flue gas (HX1) is around 76% while if reference is made to the LHV of the RMSW a broader variation is obtained, ranging from 39% in the worst case (Baseline) to almost 49% in the best case (S6). Despite this variation, the analysis of each scenario leads to a common conclusion. The best exploitation of the waste material is pursued with a 4th generation of DH network (55 °C), since the electric production is increased and thermal losses in the network are reduced.

4 CONCLUSIONS

Gasification of RMSW is a promising WtE solution that can positively valorise the end-of-life of the disposed of material. In this work, the coupling of a fluidized bed gasifier having RMSW as input material with a regenerative ORC power unit for CHP applications is presented and discussed. Three different scenarios, which correspond to different feedstock materials and syngas flow rates, are evaluated with varying working fluids. Despite it is worth mentioning that the investigated operating conditions do not correspond to the optimum ones for each working fluid, the analysis shows that the maximum electrical power production of 2.14 MW_e can be obtained with the use of toluene, while a maximum thermal power output of 7.94 MW_t can be recovered at the condenser when MDM siloxane is selected. However, if technological aspects are considered use of MM instead of MDM is suggested due to the lower condensing temperature for DH applications. Eventually, the results of the sensitivity analysis of ORC performance with DH network temperature with toluene as the working fluid reveal that electric efficiency is more sensitive to the DH network temperature than the thermal efficiency.
In conclusion the analysis shows that the combination of RMSW gasification with an ORC system is a viable alternative to incineration thus improving the environmental performance of composting facilities.

NOMENCLATURE

CHP	combined heat and power
DH	district heating

e	air excess	(-)
ER	equivalence ratio	(-)
HX	heat exchanger	
ICE	internal combustion engine	
LHV (RMSW)	lower heating value	(kJ/kg)
LHV (syngas)	lower heating value	(kJ/Nm^3)
ER	equivalence ratio	(-)
$\dot{m}_{air}$	air mass flow rate	(kg/h)
MBT	mechanical-biological treatment	
MSW	municipal solid waste	
NTU	number of thermal units	
OFMSW	organic fraction of municipal solid waste	
ORC	organic Rankine cycle	
P	pressure	(bar)
Q	thermal power	(kW)
RDF	residue-derived fuel	
RMSW	residual municipal solid waste	
s	entropy	(kJ/kg)
SP	size parameter	
ST	shell and tube	
T	temperature	(°C)
Vr	volume ratio	(-)
W	electric power	(kW)
WtE	waste to energy	
ε	heat exchanger effectiveness	(-)
η	efficiency	(-)

Subscript

air,s	stoichiometric air
cond	condenser
e	electrical
GASIF	gasifier
REG	regeneration
s	saturation
st	stoichiometric
SC	subcooling
SH	superheat
t	thermal
turb	turbine

REFERENCES

Biancini, G., Marchetti, B., Cioccolanti, L., & Moglie, M. (2022). Comprehensive Life Cycle Assessment Analysis of an Italian Composting Facility concerning Environmental Footprint Minimization and Renewable Energy Integration. *Sustainability*, *14*(22), 14961. https://doi.org/10.3390/su142214961

Biancini, G., Moradi, R., Cioccolanti, L., Marchetti, B., Moglie, M., & Del Zotto, L. (2023). A general model for air gasification of heterogenous municipal solid waste. *Energy Conversion and Management*, *278*, 116749. https://doi.org/10.1016/j.enconman.2023.116749

Braimakis, K., & Karellas, S. (2018). Energetic optimization of regenerative Organic Rankine Cycle (ORC) configurations. *Energy Conversion and Management*, *159*, 353–370. https://doi.org/10.1016/j.enconman.2017.12.093

Cavallini, A. (2017). Heat transfer and heat exchangers. In *Organic Rankine Cycle (ORC) Power Systems* (pp. 397–470). Elsevier. https://doi.org/10.1016/B978-0-08-100510-1.00013-2

Lai, N. A., Wendland, M., & Fischer, J. (2011). Working fluids for high-temperature organic Rankine cycles. *Energy*, *36*(1), 199–211. https://doi.org/10.1016/j.energy.2010.10.051

Li, C. Y., Deethayat, T., Wu, J. Y., Kiatsiriroat, T., & Wang, R. Z. (2018). Simulation and evaluation of a biomass gasification-based combined cooling, heating, and power system integrated with an organic Rankine cycle. Energy, 158, 238–255. https://doi.org/10.1016/j.energy.2018.05.206

Macchi, E., & Astolfi, M. (2017). Axial flow turbines for Organic Rankine Cycle applications. In *Organic Rankine Cycle (ORC) Power Systems* (pp. 299–319). Elsevier. https://doi.org/10.1016/B978-0-08-100510-1.00009-0

Mastellone, M. L., Zaccariello, L., & Arena, U. (2010). Co-gasification of coal, plastic waste and wood in a bubbling fluidized bed reactor. *Fuel*, *89*(10), 2991–3000. https://doi.org/10.1016/j.fuel.2010.05.019

Moradi, R., Cioccolanti, L., Del Zotto, L., & Renzi, M. (2023). Comparative sensitivity analysis of micro-scale gas turbine and supercritical CO2 systems with bottoming organic Rankine cycles fed by the biomass gasification for decentralized trigeneration. *Energy*, *266*, 126491. https://doi.org/10.1016/j.energy.2022.126491

Moradi, R., Marcantonio, V., Cioccolanti, L., & Bocci, E. (2020). Integrating biomass gasification with a steam-injected micro gas turbine and an Organic Rankine Cycle unit for combined heat and power production. *Energy Conversion and Management*, *205*, 112464. https://doi.org/10.1016/j.enconman.2019.112464

Ruiz, J. A., Juárez, M. C., Morales, M. P., Muñoz, P., & Mendívil, M. A. (2013). Biomass gasification for electricity generation: Review of current technology barriers. *Renewable and Sustainable Energy Reviews*, *18*, 174–183. https://doi.org/10.1016/j.rser.2012.10.021

Tartière, T., & Astolfi, M. (2017). A World Overview of the Organic Rankine Cycle Market. *Energy Procedia*, *129*, 2–9. https://doi.org/10.1016/j.egypro.2017.09.159

(Thanos) Bourtsalas, A. C., & Themelis, N. J. (2022). Materials and energy recovery at six European MBT plants. *Waste Management*, *141*, 79–91. https://doi.org/10.1016/j.wasman.2022.01.024

Tozlu, A., Abusoglu, A., Ozahi, E., & Anvari-Moghaddam, A. (2021). Municipal solid waste-based district heating and electricity production: A case study. Journal of Cleaner Production, 297, 126495. https://doi.org/10.1016/j.jclepro.2021.126495

Ustaoglu, A., Torlaklı, H., Ergün, A., Erdoğmuş, E., & Emin Akay, M. (2022). Advanced exergy analysis of an integrated solid waste fueled cogeneration system based on organic Rankine Cycle for different working fluids. Energy Conversion and Management, 270, 116294. https://doi.org/10.1016/j.enconman.2022.116294

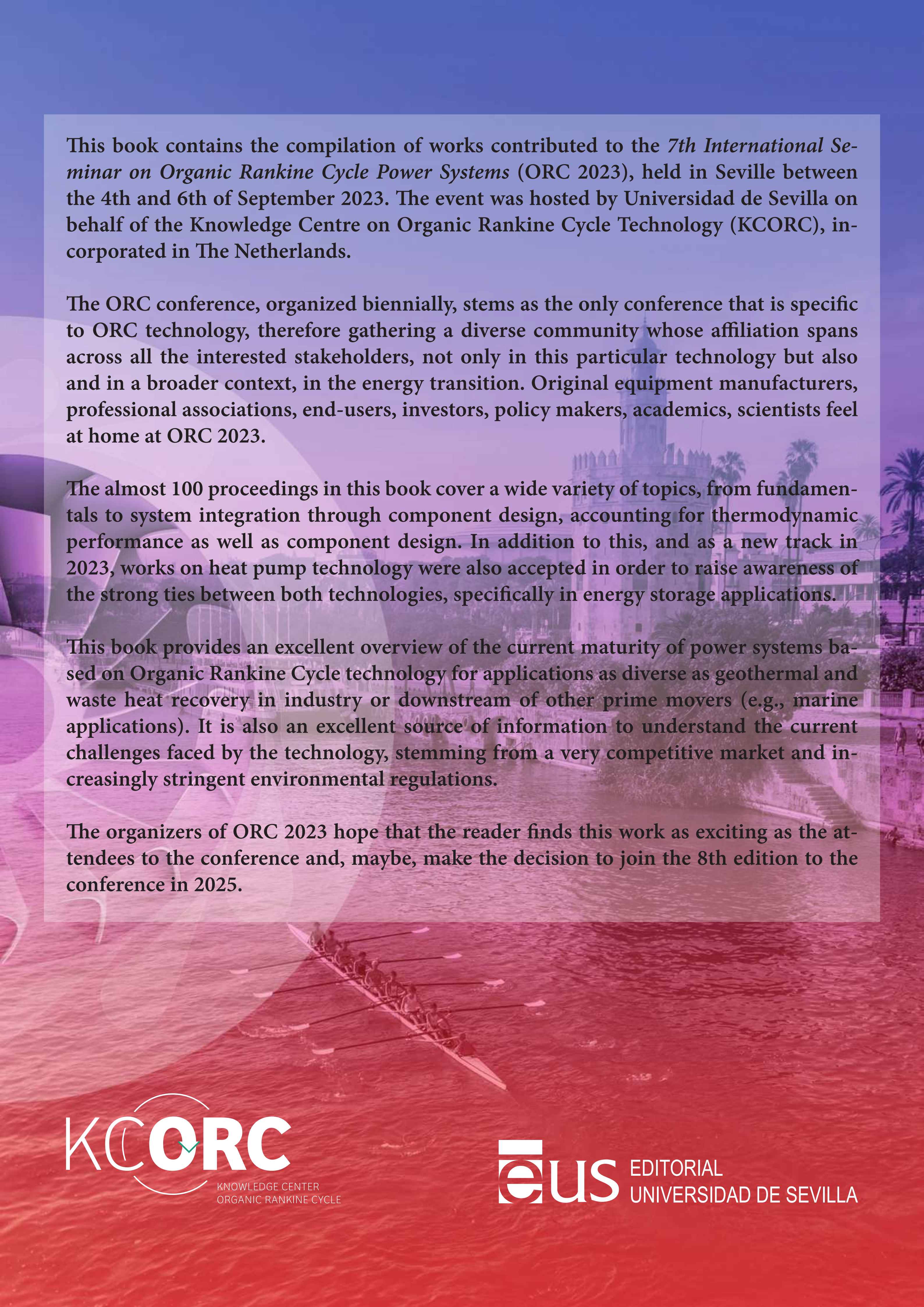
Vankeirsbilck, I., Vanslambrouck, B., Gusev, S., & De Paepe, M. (2011). Organic Rankine cycle as efficient alternative to steam cycle for small scale power generation. *HEFAT 2011*.

Vescovo, R., & Spagnoli, E. (2017). High Temperature ORC Systems. *Energy Procedia*, *129*, 82–89. https://doi.org/10.1016/j.egypro.2017.09.160

Win, M. M., Asari, M., Hayakawa, R., Hosoda, H., Yano, J., & Sakai, S. (2019). Characteristics of gas from the fluidized bed gasification of refuse paper and plastic fuel (RPF) and wood biomass. *Waste Management*, *87*, 173–182. https://doi.org/10.1016/j.wasman.2019.02.002

Yuan, M., Thellufsen, J. Z., Sorknæs, P., Lund, H., & Liang, Y. (2021). District heating in 100% renewable energy systems: Combining industrial excess heat and heat pumps. *Energy Conversion and Management*, *244*, 114527. https://doi.org/10.1016/j.enconman.2021.114527

Zhang, X., & Li, Y. (2023). An examination of super dry working fluids used in regenerative organic Rankine cycles. *Energy*, *263*, 125931. https://doi.org/10.1016/j.energy.2022.125931



This book contains the compilation of works contributed to the *7th International Seminar on Organic Rankine Cycle Power Systems* (ORC 2023), held in Seville between the 4th and 6th of September 2023. The event was hosted by Universidad de Sevilla on behalf of the Knowledge Centre on Organic Rankine Cycle Technology (KCORC), incorporated in The Netherlands.

The ORC conference, organized biennially, stems as the only conference that is specific to ORC technology, therefore gathering a diverse community whose affiliation spans across all the interested stakeholders, not only in this particular technology but also and in a broader context, in the energy transition. Original equipment manufacturers, professional associations, end-users, investors, policy makers, academics, scientists feel at home at ORC 2023.

The almost 100 proceedings in this book cover a wide variety of topics, from fundamentals to system integration through component design, accounting for thermodynamic performance as well as component design. In addition to this, and as a new track in 2023, works on heat pump technology were also accepted in order to raise awareness of the strong ties between both technologies, specifically in energy storage applications.

This book provides an excellent overview of the current maturity of power systems based on Organic Rankine Cycle technology for applications as diverse as geothermal and waste heat recovery in industry or downstream of other prime movers (e.g., marine applications). It is also an excellent source of information to understand the current challenges faced by the technology, stemming from a very competitive market and increasingly stringent environmental regulations.

The organizers of ORC 2023 hope that the reader finds this work as exciting as the attendees to the conference and, maybe, make the decision to join the 8th edition to the conference in 2025.

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