Centrum
Rzeczoznawstwa
Budowlanego

Open Access Journal
Modern Engineering 4 (2024) 11-24
journal homepage: https://mengineering.eu/

Impact of Electric Generator Replacement on the Performance of an ORC System Using R600a as the Working Fluid

Adam SZELĄGOWSKI*[1], Katarzyna KWIATKOWSKA[1]

[1]Warsaw University of Technology, Institute of Heat Engineering, Warsaw, Poland

Abstract

ORC (Organic Rankine Cycle) is a device that, utilizing the Rankine cycle, employs a working fluid other than water. The proper functioning of the system relies on the correct selection of individual components, such as the condenser, evaporator, regenerator, pump, and expander. It often turns out that the choice of the electrical generator is also a crucial aspect to ensure the proper operation of the device. This article presents the results of studies on a device that, in its first version, used a generator with a nominal power of 0.75 kW and, in its second version, 2.2 kW. The tests were conducted on the device's operation both with and without the regenerator. The results show that it is impossible to select a configuration that achieves the best performance under all operating conditions. Therefore, the choice of the generator is closely linked to the anticipated operating conditions.

Key words: Organic Rankine Cycle, ORC, energy efficiency, electric generator.

1. Introduction

Organic Rankine Cycle (ORC) systems are thermodynamic systems designed to convert low-grade thermal energy into mechanical work or electricity [1]. Unlike traditional Rankine cycles, ORC systems utilize organic working fluids with favorable thermodynamic properties, such as low boiling points and high molecular weights, making them suitable for applications with lower-temperature heat sources [2], [3]. These systems are widely employed in waste heat recovery, geothermal energy utilization, and solar power applications, where efficient energy conversion is critical [4], [5].

In the analyzed ORC system (Fig. 1), isobutane (R600a) is used as the working fluid. The heat source is an oil-fired boiler operating at 90°C, while the heat sink is a refrigeration unit employing glycol as the cooling fluid, maintaining a temperature of 15°C. The theoretical evaporation pressure is approximately 12.5 bar. The working fluid undergoes phase change in the evaporator, flows through the regenerator, and then expands in an expander connected to an electric generator. Valves placed before the heat exchangers enable the inclusion or exclusion of the regenerator from the system configuration.

After expansion, the working fluid enters the condenser, where it transitions into the liquid phase and is being pumped back to the evaporator. For thermodynamic analysis, the condensation and evaporation temperatures are set at 20°C and 80°C, respectively. The system is managed by a Siemens control panel, which monitors key operational parameters at various measurement points, with data recorded via a dedicated measurement card.

---

* **Corresponding author:** E-mail address: (adam.szelagowski@pw.edu.pl) Adam SZELĄGOWSKI

Received 5 November 2024
Available online 15 December 2024
ISSN 2450-5501
Published by Centrum Rzeczoznawstwa Budowlanego

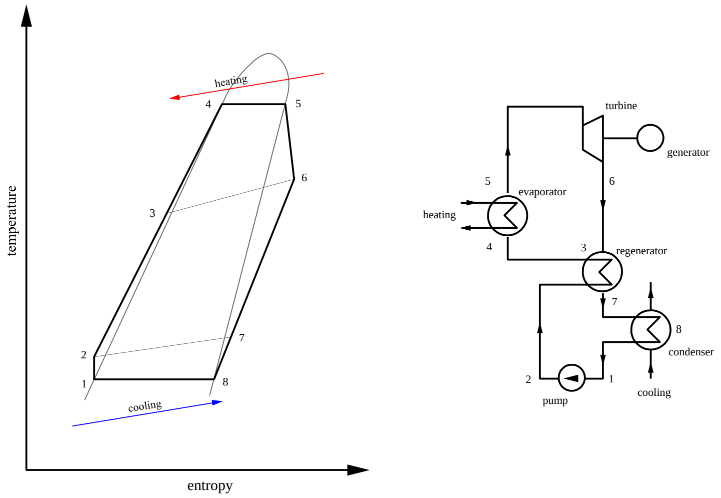

Fig. 1. Standard ORC system

1.1. ORC working fluids

The choice of working fluid is one of the most critical factors influencing the efficiency, safety, and applicability of Organic Rankine Cycle (ORC) systems [6]. Working fluids for ORC systems are typically organic compounds with thermodynamic properties that make them suitable for low- to medium-temperature heat recovery. These fluids are selected based on criteria such as boiling point, thermal stability, environmental impact, and compatibility with system components. Commonly used working fluids in ORC systems can be categorized into several groups:

1.1.1. Hydrocarbons

Hydrocarbons such as isobutane (R600a), propane (R290), and pentane (R601) are frequently used in ORC systems. These fluids have low boiling points and are highly effective in low-temperature applications. Isobutane, in particular, is widely used due to its favorable thermodynamic properties and widespread availability. However, hydrocarbons are flammable, which requires appropriate safety measures [7] [8].

1.1.2. Refrigerants

Synthetic refrigerants like R245fa, R134a, and R1234yf are commonly employed in ORC systems due to their stability and compatibility with heat exchangers and other components. Refrigerants are particularly effective in systems with moderate heat source temperatures. In recent years, low-global-warming-potential (GWP) refrigerants have gained attention to meet environmental regulations.

1.1.3. Siloxanes

Siloxanes such as MM (hexamethyldisiloxane) are used in ORC systems operating at higher temperatures. These fluids exhibit high thermal stability and low viscosity, making them suitable for applications like geothermal energy and solar power. However, siloxanes can be expensive and require specialized handling [9].

1.1.4. Aromatic Hydrocarbons

Aromatic hydrocarbons such as toluene and benzene are used in high-temperature ORC systems. They have high critical temperatures and pressures, making them suitable for heat sources above 300°C. However, these fluids can be toxic and environmentally hazardous, limiting their use to specific industrial applications [10].

1.1.5. Alcohols

Alcohols like methanol and ethanol are occasionally used in ORC systems due to their low boiling points and compatibility with certain system designs. However, their use is limited by their flammability and potential for corrosive effects on system components [11].

Due to regulatory requirements aimed at ensuring environmental sustainability and compliance with safety standards, the decision was made to utilize R600a, a hydrocarbon-based refrigerant, as an appropriate working fluid. This choice aligns with modern directives and policies that prioritize low global warming potential (GWP) and ozone depletion potential (ODP), making R600a a favorable option in the context of environmentally friendly and energy-efficient applications. Its chemical properties, combined with regulatory incentives, have positioned R600a as a reliable and sustainable solution in various industrial and domestic systems.

2. Experimental apparatus

The diagram (Fig. 2.) depicts the schematic of the investigated Organic Rankine Cycle (ORC) system, including all measurement points and instrumentation. Key components such as the heat source, evaporator, expander, condenser, regenerative heat exchanger, and liquid receiver are highlighted. Measurement points for temperature (T), pressure (p), and flow rate (f) are strategically positioned throughout the system to monitor its performance. Additional elements like the pump, filter-drier, and electrical resistors for energy dissipation are also shown, along with critical control and regulation components, including solenoid valves (ZS) and electronic modules (EM). The system is designed for experimental analysis of ORC efficiency and thermodynamic parameters. In the Fig. 3. There is shown view of experimental apparatus.

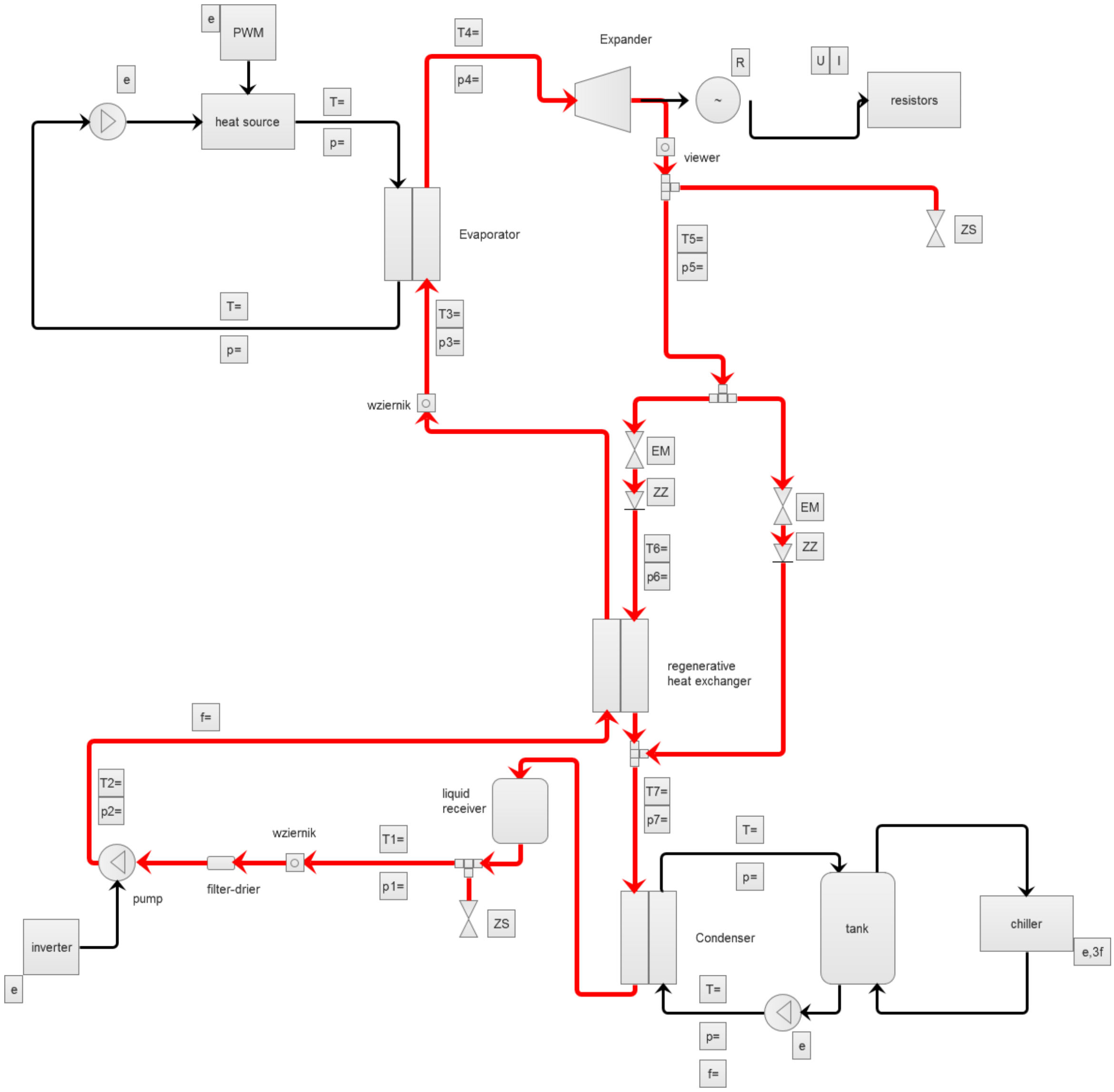

Fig. 2. Experimental setup

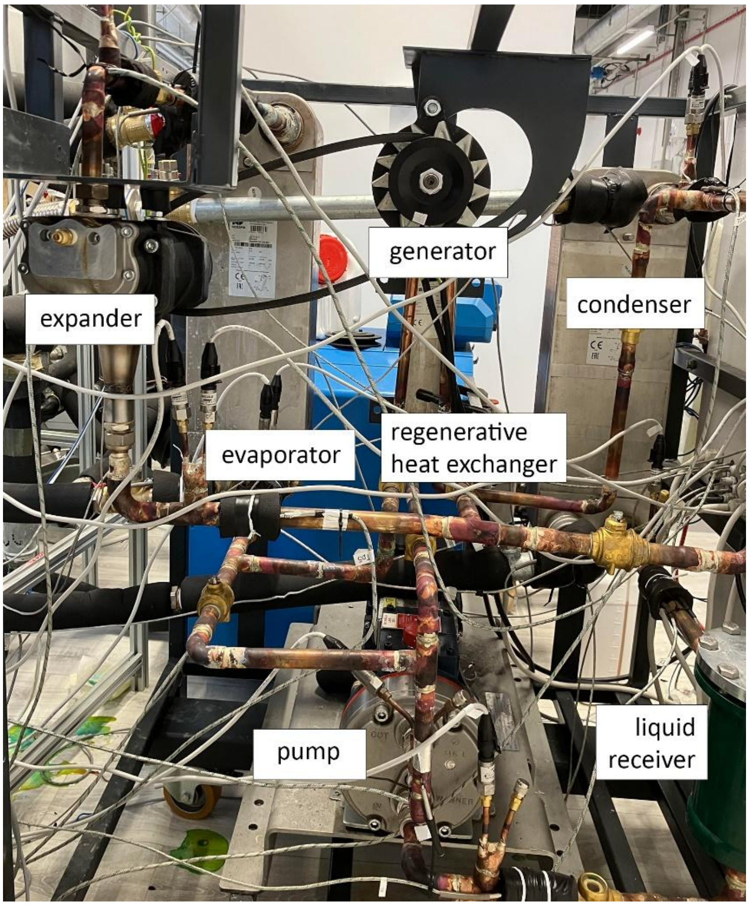

Fig. 3. Experimental stand view

3. Results

Experiments was made for cases:

- Generator: nominal capacity 750 W (regeneration)
- Generator: nominal capacity 750 W (without regeneration)
- Generator: nominal capacity 2200 W (regeneration)
- Generator: nominal capacity 2200 W(without regeneration)

3.1. Generator: nominal capacity 750 W (regeneration)

In the first case, a scenario was studied where a generator with a nominal power of 750 W was installed, and the system operated with heat recovery. During the experiment, the rotational speed of the working fluid pump was varied. Experimental results are presented in Figures 4, 5, and 6, showing the startup process, changes in pump rotational speed, and the resulting electrical power generated. In each case, efforts were made to maintain the expander's rotational speed at approximately 3000 rpm. Figure 7, on the other hand, illustrates the achieved efficiency results. Both thermal efficiency and overall efficiency are presented, the latter being the ratio of the generated electrical power to the heating costs of the working fluid in the evaporator.

It was observed that the highest power output was achieved at 50% pump power, reaching up to 550 W of electrical power. Regarding efficiency, the thermal efficiency was relatively stable, maintaining a level of 5%, while the overall efficiency ranged between 3% and 2%.

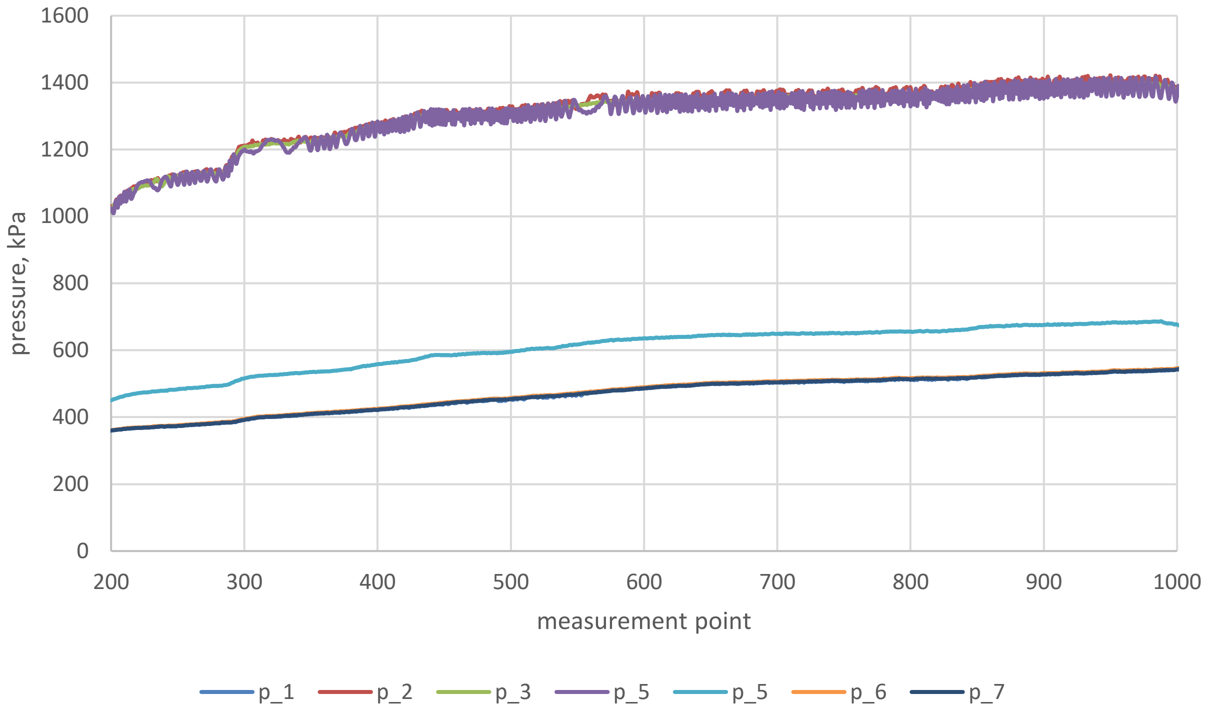

Fig 4. Measured pressure value

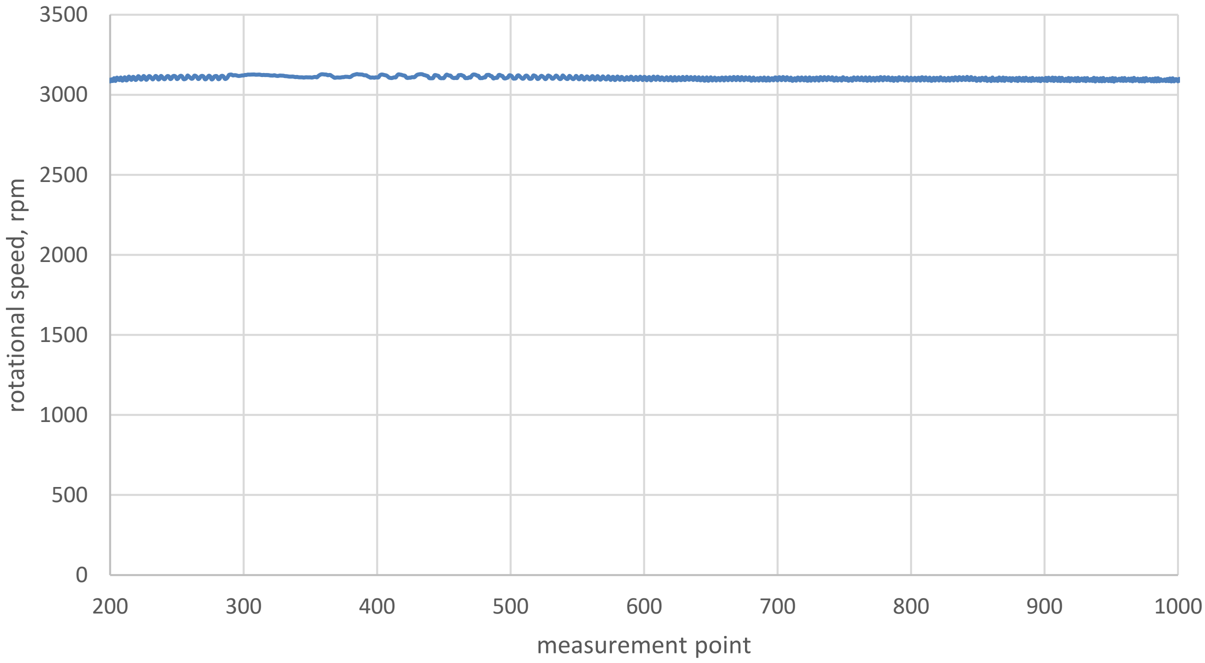

Fig. 5. Measured rotational speed

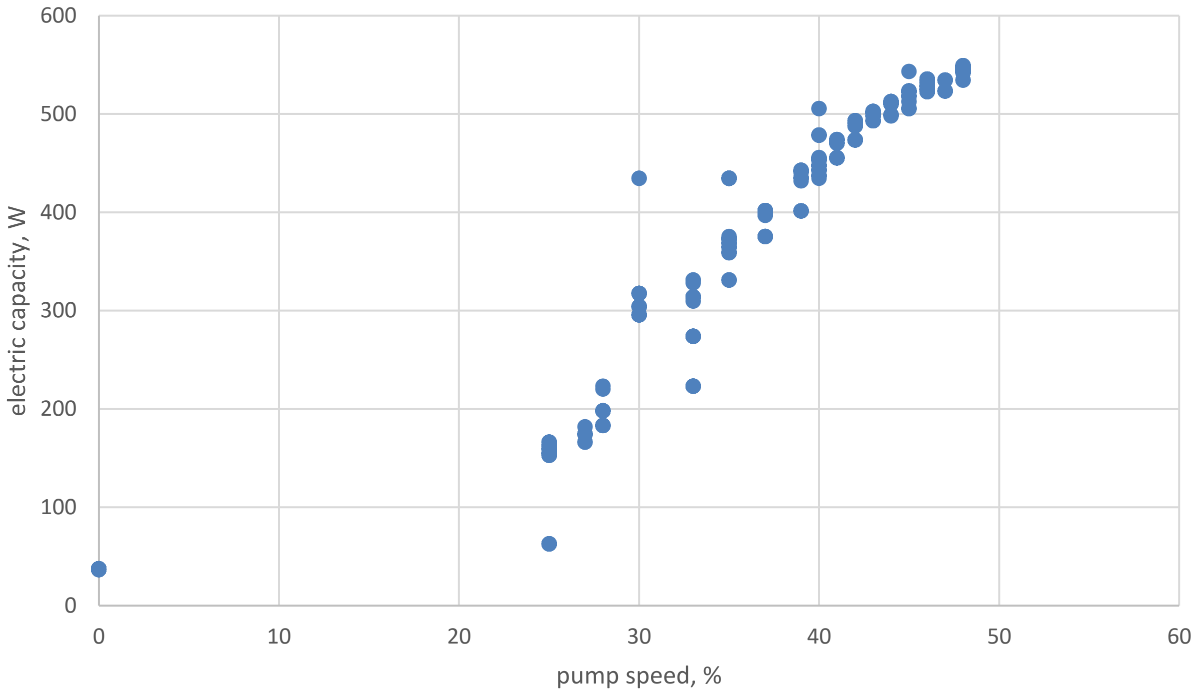

Fig. 6. Obtained electric capacity according to pump speed

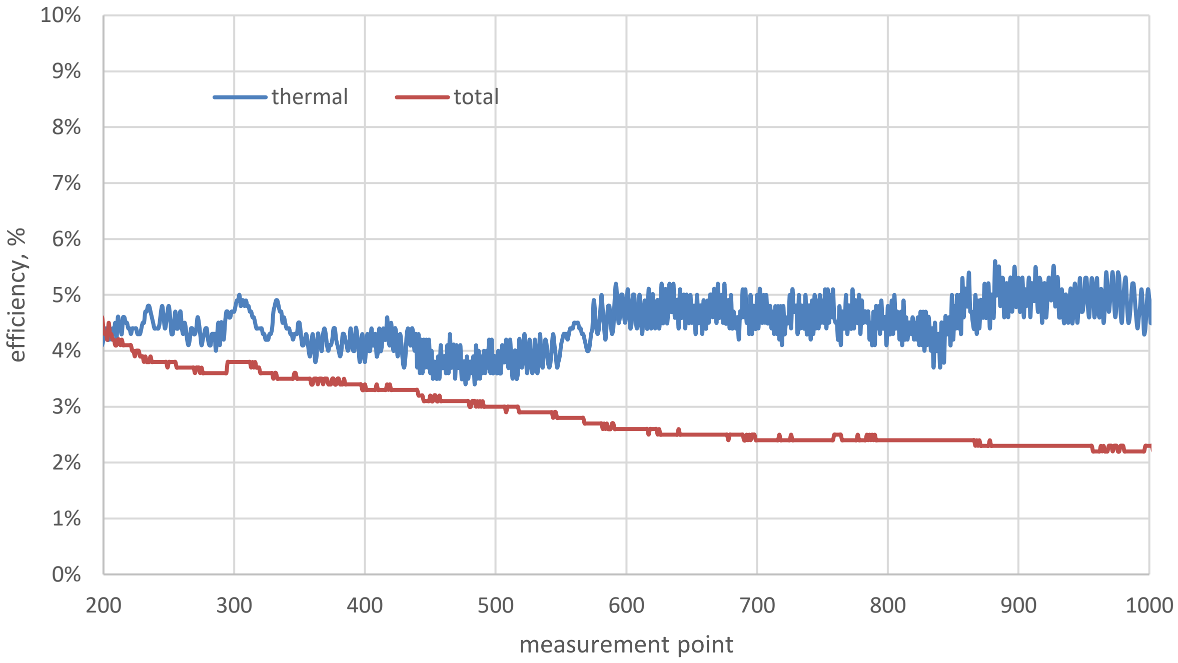

Fig. 7. Obtained efficiency

3.2. Generator: nominal capacity 750 W (without regeneration)

In the second case, the system's performance without a regenerator was analyzed. The results are presented in Figures 8 to 11. It was observed that the power output from the generator was higher, reaching up to 1200 W, but the thermal efficiency dropped to 3%, and the overall efficiency decreased to 2%. Nonetheless, maximizing the generated power is more important than achieving the highest possible efficiency.

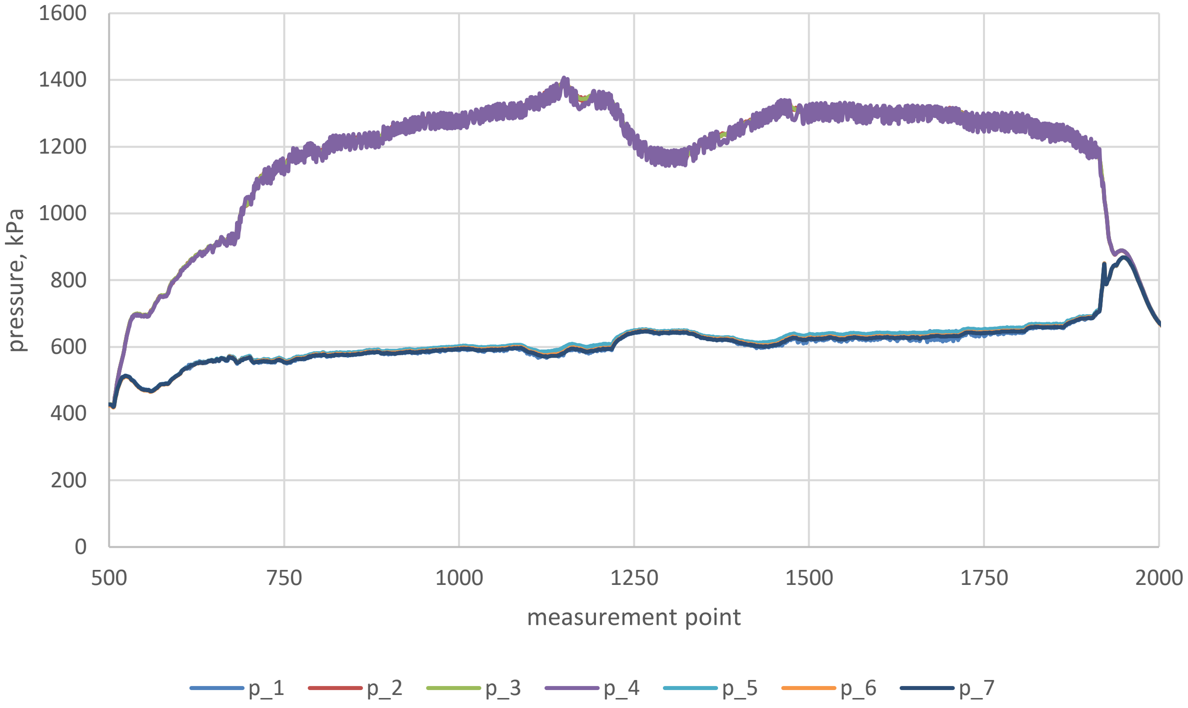

Fig 8. Measured pressure value

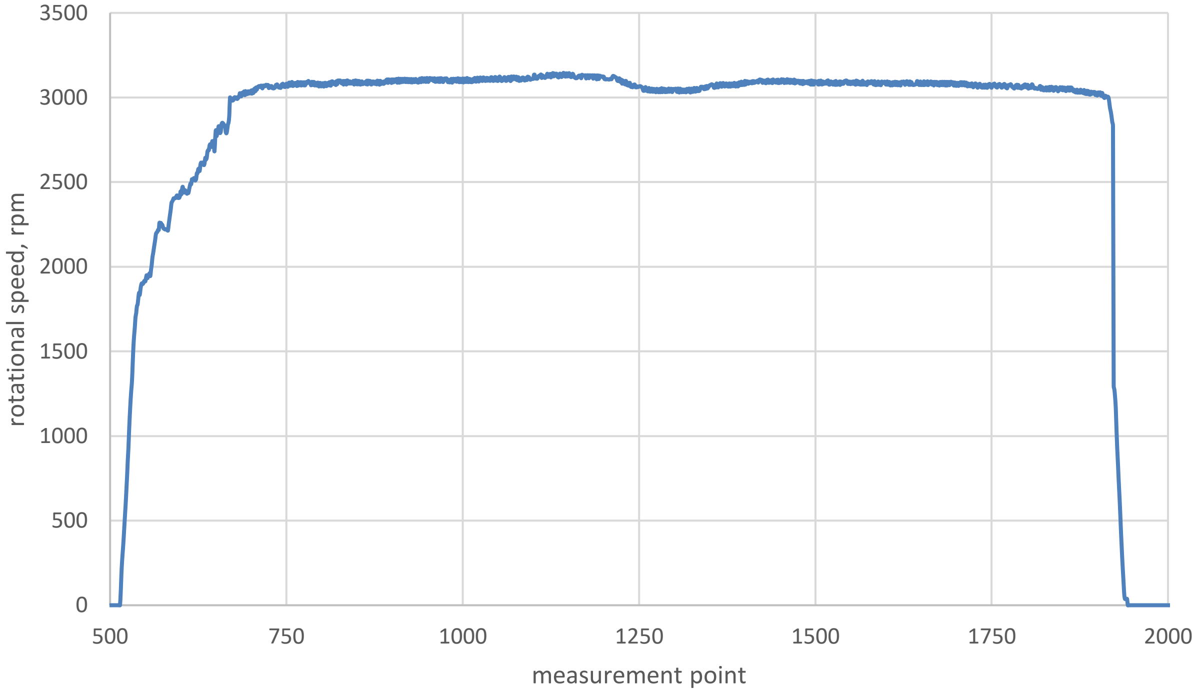

Fig. 9. Measured rotational speed

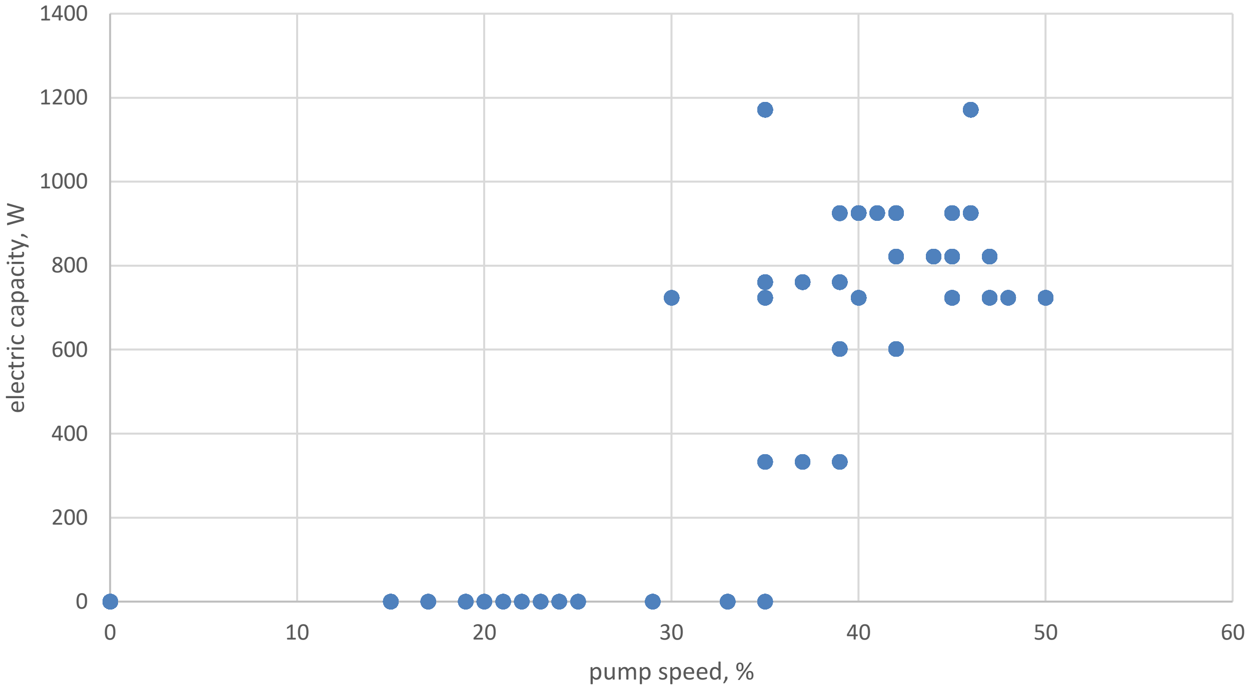

Fig. 10. Obtained electric capacity according to pump speed

Fig. 11. Obtained efficiency

3.3. Generator: nominal capacity 2200 W (regeneration)

In the next step, the generator was replaced. This time, a generator with a nominal power of 2200 W was used. The initial tests with this generator were conducted for a system operating with a regenerator. The results are presented in Figures 12 to 15. Compared to the analogous operation with the 750 W generator, higher power output was achieved—reaching up to 1000 W—but the efficiency was significantly lower: 3%

thermal efficiency and 2% overall efficiency. The maximum power was also achieved at lower pump rotational speeds compared to the first generator.

.

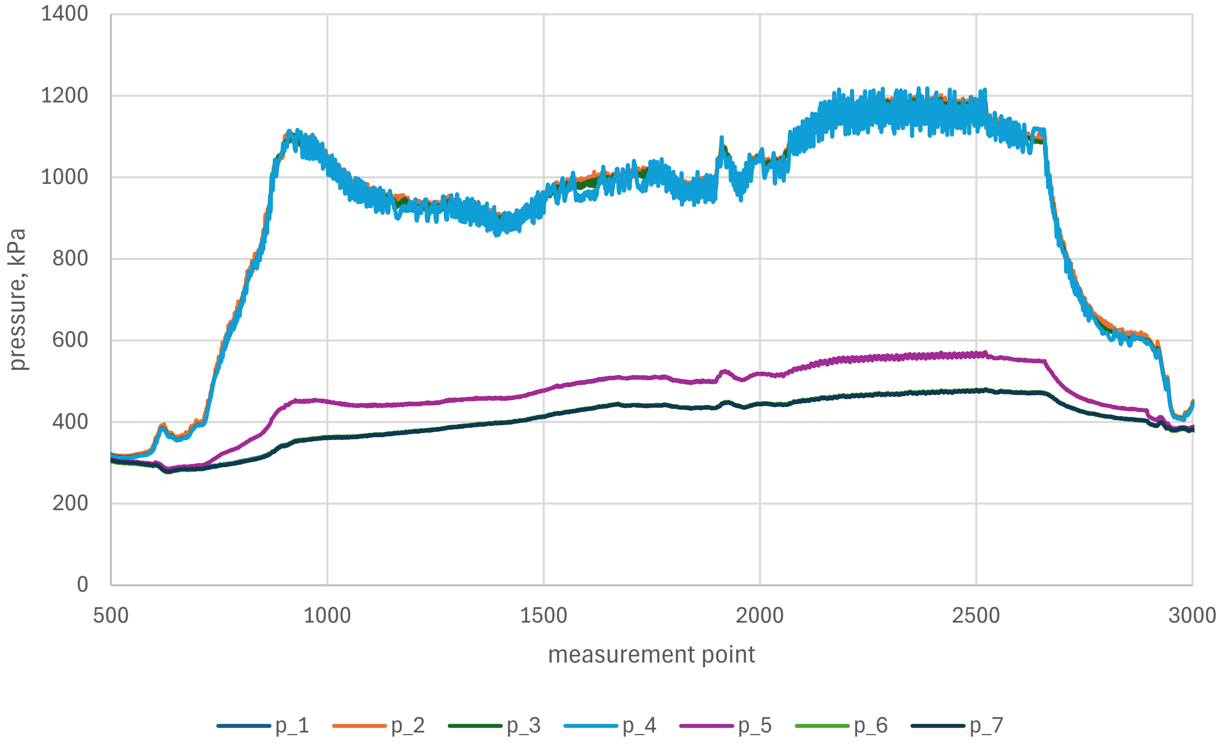

Fig 12. Measured pressure value

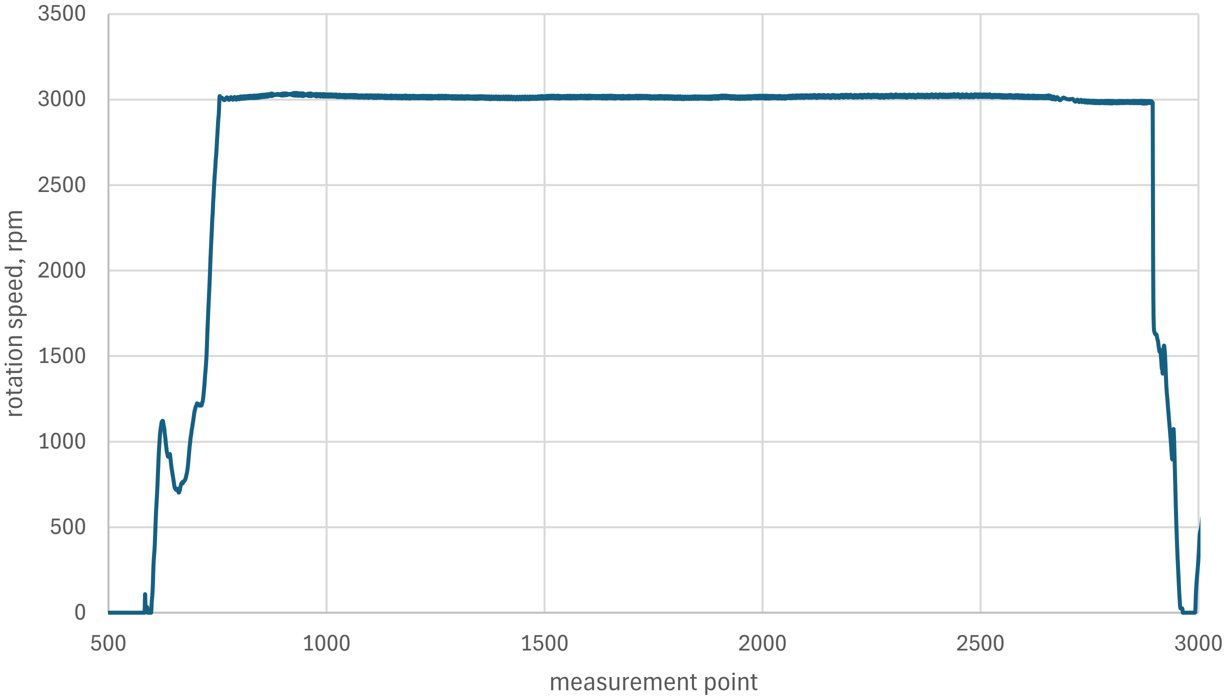

Fig. 13. Measured rotational speed

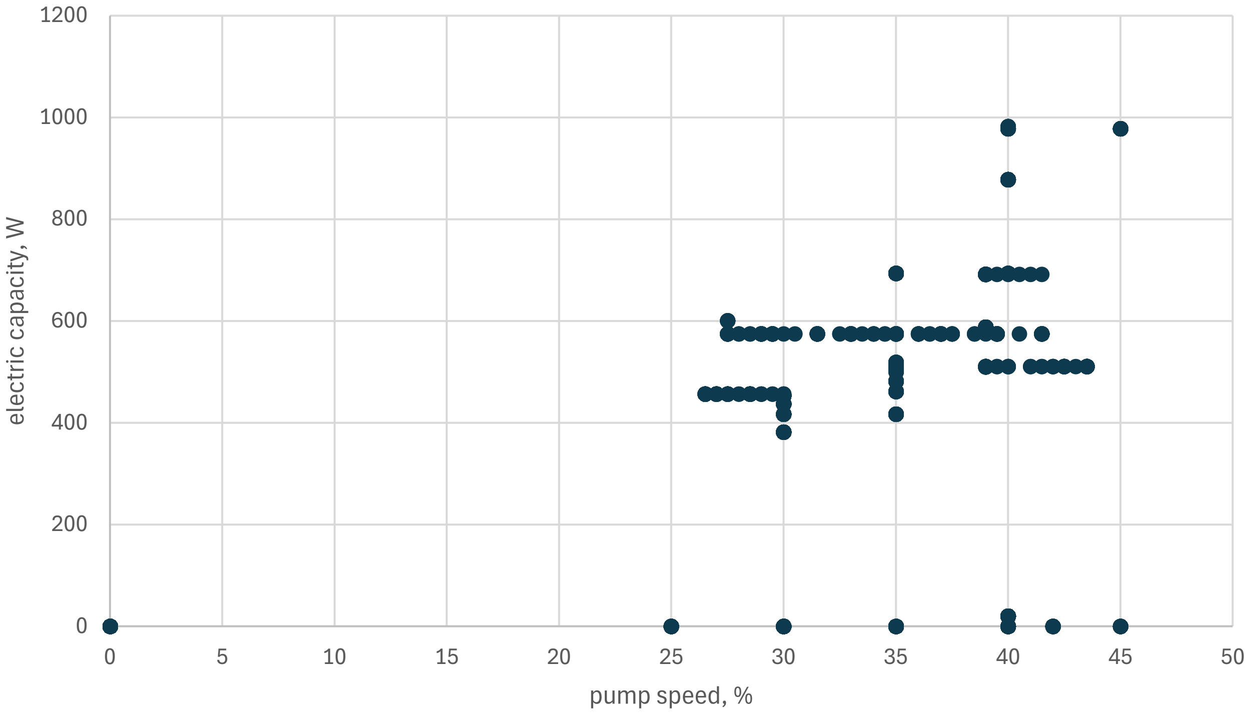

Fig. 14. Obtained electric capacity according to pump speed

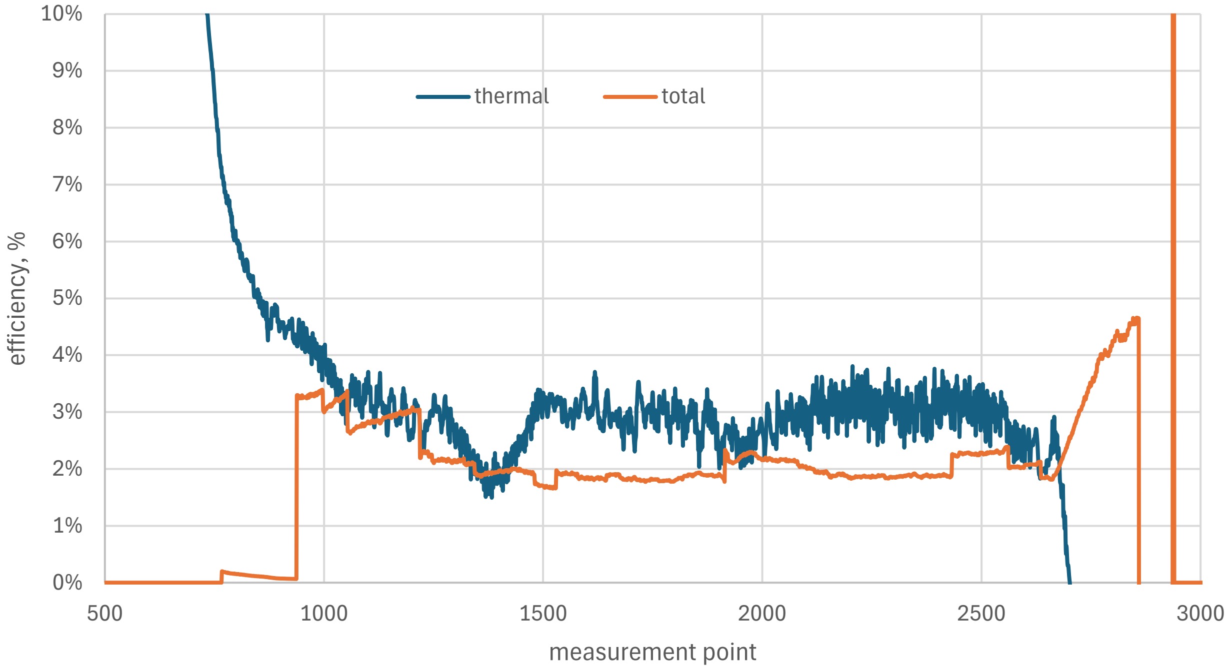

Fig. 15. Obtained efficiency

3.4. Generator: nominal capacity 2200 W (without regeneration)

The final case studied was the scenario in which the system operated without a regenerator. This time, the opposite effect was observed compared to the 750 W generator. Specifically, both the power output and efficiency dropped drastically when operating with a regenerator. The experimental results are presented in Figures 16 to 19.

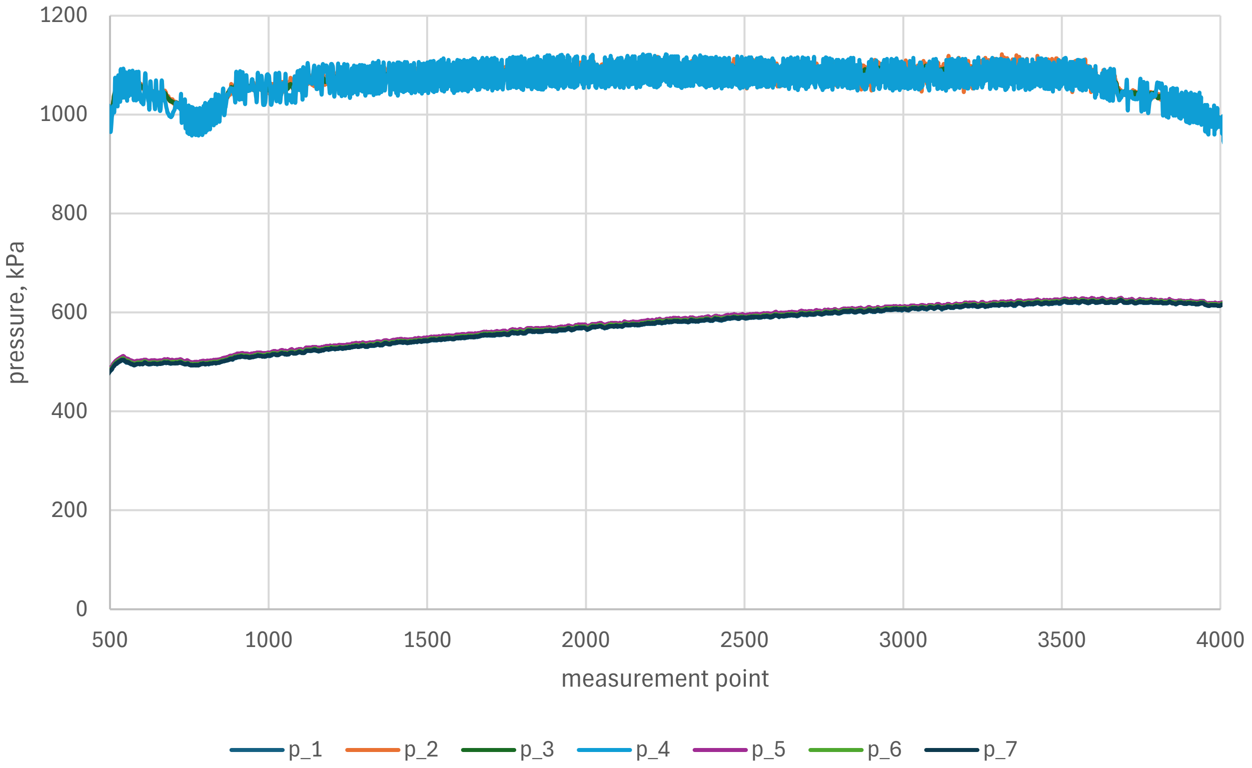

Fig. 16. Measured pressure value

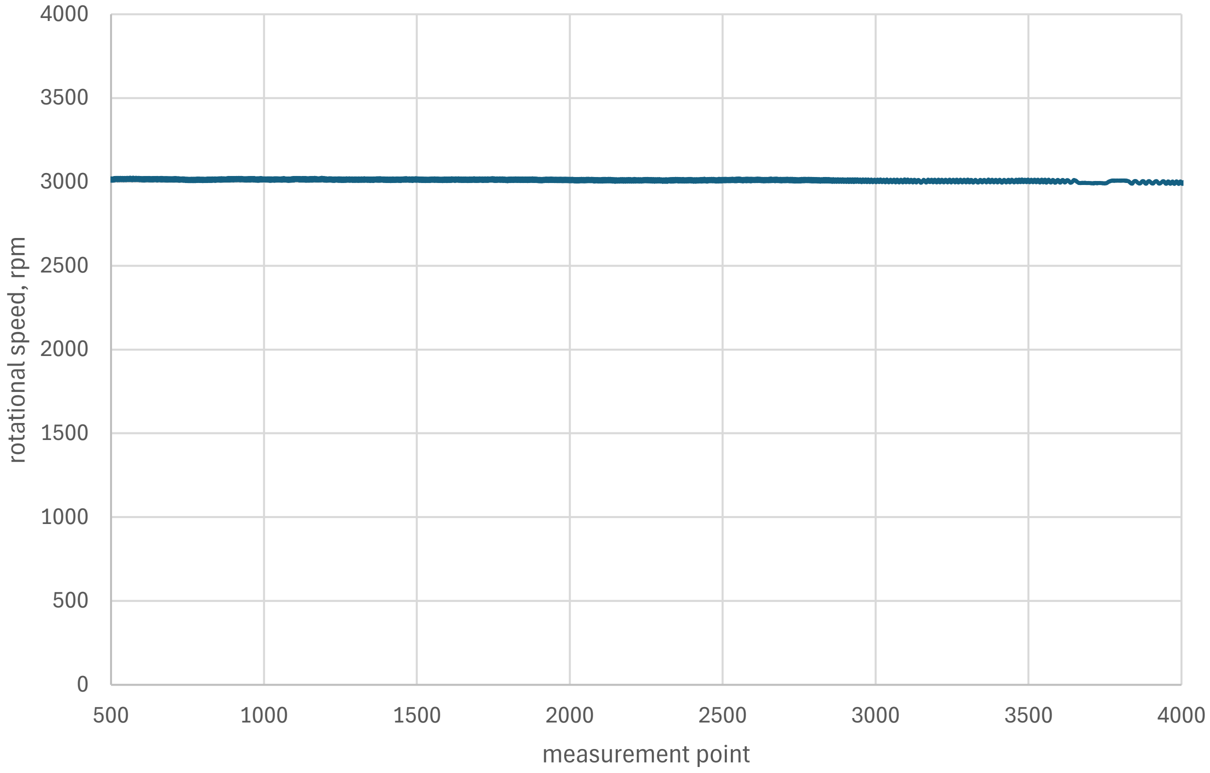

Fig. 17. Measured rotational speed

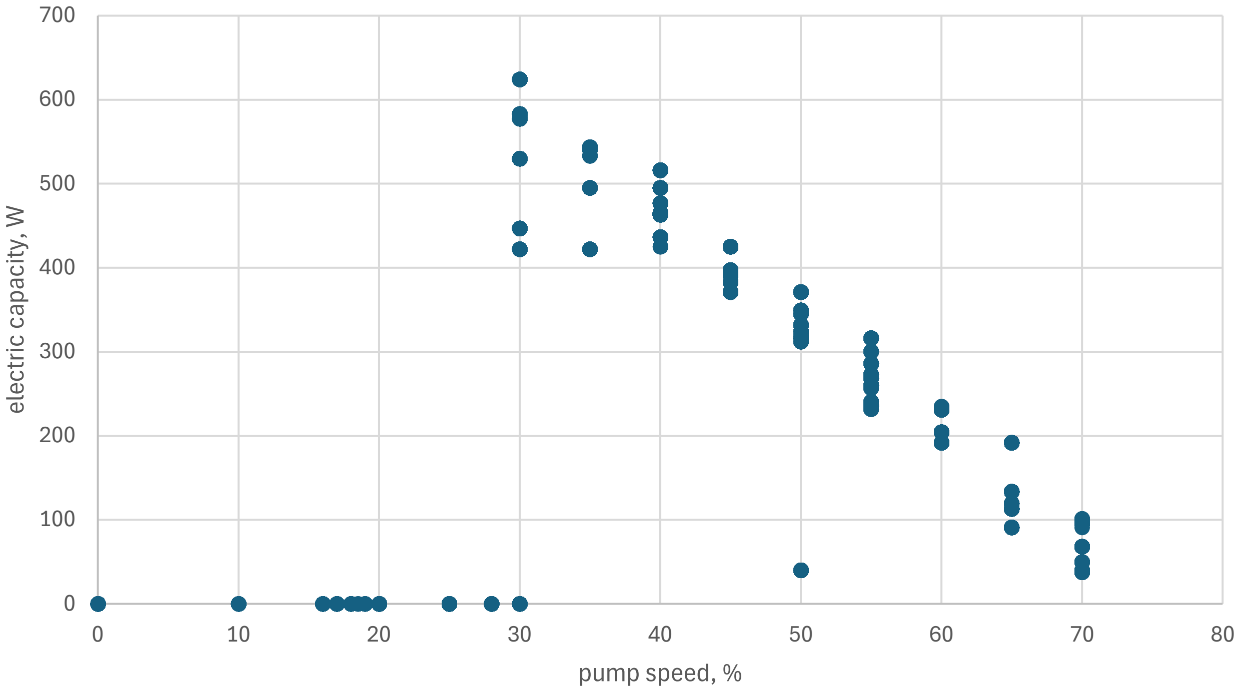

Fig. 18. Obtained electric capacity according to pump speed

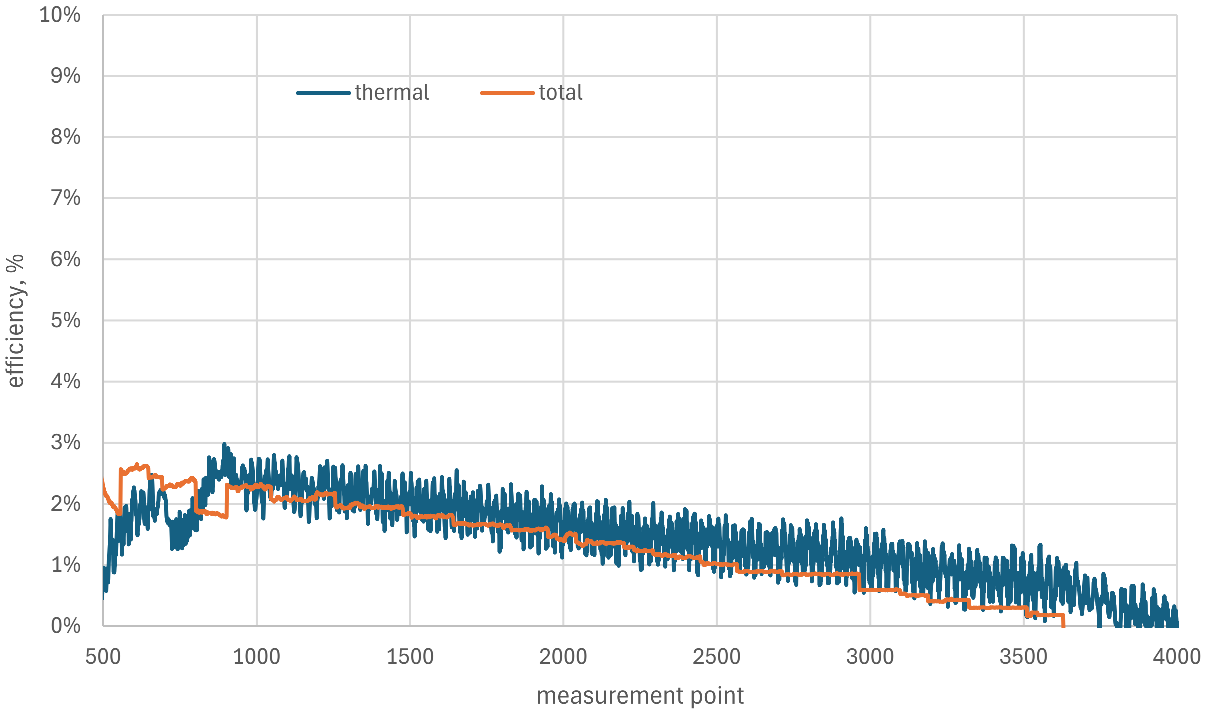

Fig. 19. Obtained efficiency

4. Conclusions

The study investigated the performance of a system equipped with different generators under varying configurations, focusing on power output and efficiency.

In the first scenario, a 750 W nominal power generator was tested with the system operating with heat recovery. By adjusting the rotational speed of the working fluid pump, the system achieved a maximum electrical power output of 550 W at 50% pump power. Thermal efficiency was stable at 5%, while overall efficiency ranged between 2% and 3%. Efforts were made to maintain the expander's rotational speed at 3000 rpm. The results demonstrated that thermal and overall efficiency were relatively low, but the generated power was consistent.

The second scenario examined the system without a regenerator. In this configuration, the generator achieved a significantly higher power output of up to 1200 W. However, thermal efficiency dropped to 3%, and overall efficiency decreased to 2%. Despite the lower efficiencies, the focus was on maximizing power generation rather than achieving high efficiency.

Subsequently, the 750 W generator was replaced with a 2200 W nominal power generator. Initial tests with this generator were conducted for the system operating with a regenerator. Compared to the 750 W generator, the 2200 W system achieved a higher power output of up to 1000 W. However, the thermal efficiency dropped to 3%, and overall efficiency was just 2%. Additionally, the maximum power output was achieved at lower pump rotational speeds than with the 750 W generator.

The final scenario involved the 2200 W generator operating without a regenerator. Unlike the 750 W generator, the absence of a regenerator resulted in a drastic decline in both power output and efficiency. This configuration produced poorer results, underscoring the importance of system optimization for different generator specifications.

Across all experiments, a clear trade-off between power generation and efficiency was observed. Configurations with higher power output often exhibited lower thermal and overall efficiencies. While the 750 W generator with heat recovery demonstrated stable efficiency, the 2200 W generator showed potential for higher power generation but required careful management of operational parameters. The experiments highlight the need to balance power output and efficiency based on the specific goals of the system.

ACKNOWLEDGMENT

The study was financed by the National Centre for Research and Development (Poland) in the framework of the grant No MAZOWSZE/0181/19.

References

[1] A. Grzebielec, A. Szelągowski, P. Łapka, Ł. Cieślikiewicz i M. Seredyński, „The use of a genetic algorithm to determine the optimal operating conditions for a low-temperature orc system,” w *12th ICEE SELECTED PAPERS*, Wilno, Litwa, 2023.

[2] A. Stainchaouer, C. Schifflechner, C. Wieland, G. Sakalis i H. Spliethoff, „Evaluating long-term operational data of a Very Large Crude Carrier: Assessing the diesel engines waste heat potential for integrating ORC systems,” *Applied Thermal Engineering*, 2024.

[3] X. Wu, L. Lin, L. Xie, J. Chen i L. Shan, „Fast robust optimization of ORC based on an artificial neural network for waste heat recovery,” *Energy*, tom 301, 2024.

[4] N. Pan, C. Shen i S. Wang, „Experimental study on forced thermoacoustic oscillation driven by loudspeaker,” *Energy Conversion and Management*, tom 65, pp. 84-91, 2013.

[5] M. Asim, S. Khan, S. Ali Khan, T. Baig, M. Imran, A. W. Zia, F. Riaz i M. K. Leung, „Thermal analysis and optimal fluid selection for the novel integrated vapor compression cycle and ORC system for ultra-low grade waste heat recovery using the desuperheating method,” *Energy Nexus*, tom 17, 2025.

[6] P. Lykas, K. Atsonios, A. Gkountas, P. Bakalis, D. Manolakos, P. Grammelis, G. Itskos i N. Nikolopoulos, „Energy, exergy, and economic comparison of ORC with quasi-isothermal expansion with other ORC designs for low-grade waste heat recovery,” *Thermal Science and Engineering Progress*, tom 55, 2024.

[7] A. Grzebielec, A. Szelągowski, Ł. Cieslikiewicz, P. Łapka i M. Seredyński, „Experimental study of the ORC system with isobutane (R600a) as a working fluid,” w *11. European Conference on Renewable Energy Systems Ecres 2023. Proceedings, 2023*, Riga, 2023.

[8] W. Gao, Z. Wu, Z. Tian i Y. Zhang, „Experimental investigation on an R290-based organic Rankine cycle utilizing cold energy of liquid nitrogen,” *Applied Thermal Engineering,* tom 202, 2022.

[9] G. Cammi , C. C. Conti, S. Andrea i A. Guardone, „Experimental characterization of nozzle flow expansions of siloxane MM for ORC turbines applications,” *Energy,* tom 218, 2021.

[10] X. Dai, L. Shi, Q. An i W. Qian, „Screening of hydrocarbons as supercritical ORCs working fluids by thermal stability,” *Energy Conversion and Management,* tom 126, pp. 632-637, 2016.

[11] M. Bahrami, . F. Pourfayaz i A. Kasaeian, „Low global warming potential (GWP) working fluids (WFs) for Organic Rankine Cycle (ORC) applications,” *Energy Reports,* tom 8, 2022.