Zakład Dynamiki
i Diagnostyki Turbin

Institute of Fluid-Flow Machinery, Polish Academy of Sciences
Centre of Mechanics of Machines
Department of Turbine Dynamics and Diagnostics

EXPERIMENTAL INVESTIGATION OF A RADIAL MICROTURBINE IN ORGANIC RANKINE CYCLE SYSTEM WITH HFE7100 AS WORKING FLUID

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Outline of presentation

1. Introduction - motivation
2. Experimental setup
   - investigated cycle
   - heating cycles
   - radial microturbine
   - cooling cycle
3. Experimental results
4. Conclusions

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1. INTRODUCTION - MOTIVATION

- In the recent years fossil fuel consumption has been increasing and the burning of fossil fuel is said to be a major contributor towards global warming, acid rains, air, water and soil pollution, forest devastation and emissions from radioactive substances.

- Highly efficient CHP generation systems were provided in the European Directive 2004/8/EC in order to attain primary savings in the internal energy market.

- The Directive 2009/28/WE, approved by the European Union, has committed the majority of its Member States to increase the share of renewable energy sources (RES) in total energy consumption to 20% by 2020 (15% in Poland).

2. EXPERIMENTAL SETUP

The co-generative micro power plant
with the HFE 7100 as a working fluid was designed and built for the purposes of experimental investigations. The values of the main cycle parameters were as follows:

- heat output: 20 - 30 kW,
- electric output: 2 - 3 kW
- medium mass flow rate: 170 g/s,
- absolute pressure at turbine inlet: 12 bar,
- temperature at turbine inlet: 162 ^{o}C,
- absolute pressure behind the turbine: 1.2 bar (the saturation temperature is equal to about 65 ^{o}C).

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2. EXPERIMENTAL SETUP

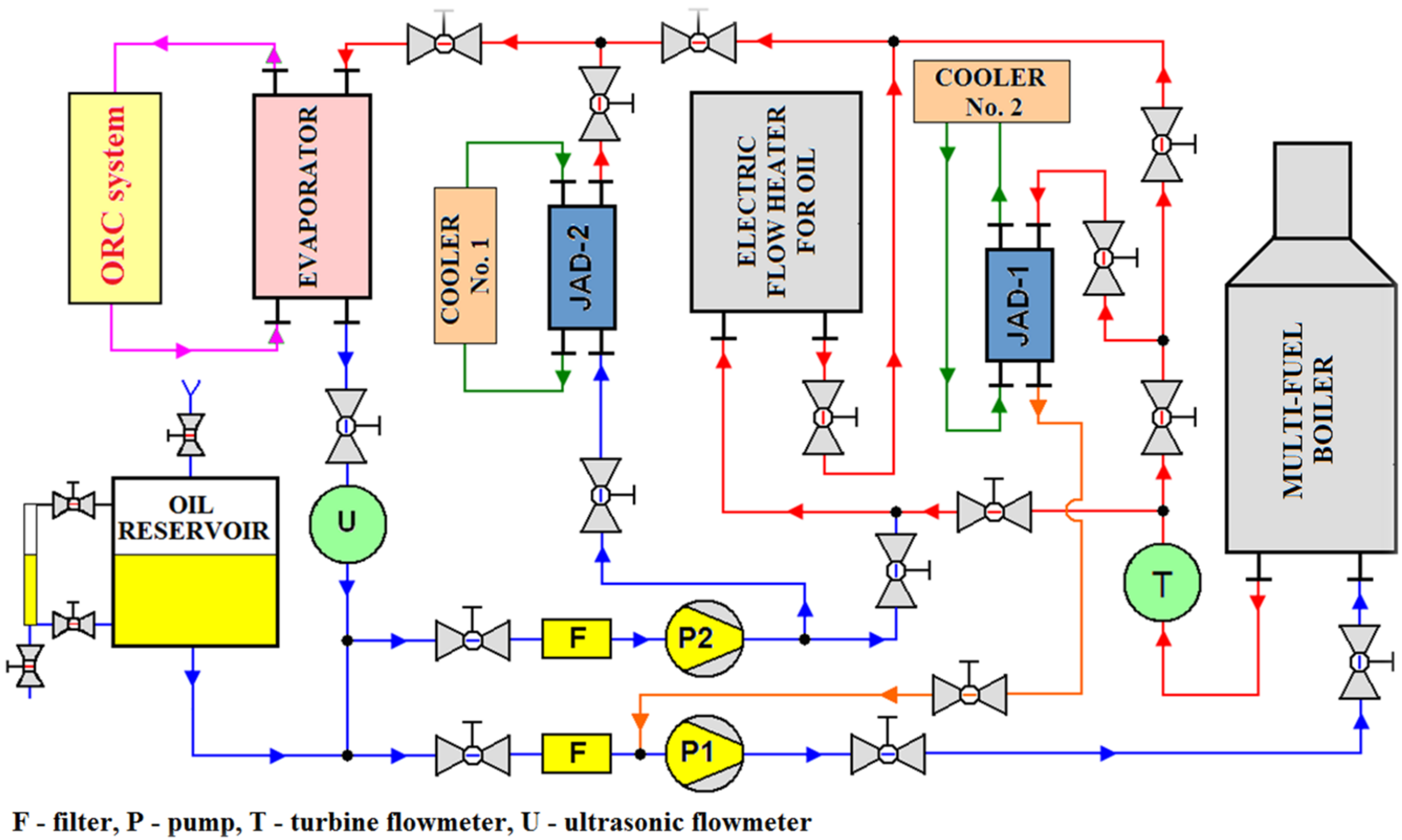

Fig. 1. Scheme of a heating cycle with a multi-fuel boiler or electric flow heater for thermal oil and heat exchangers

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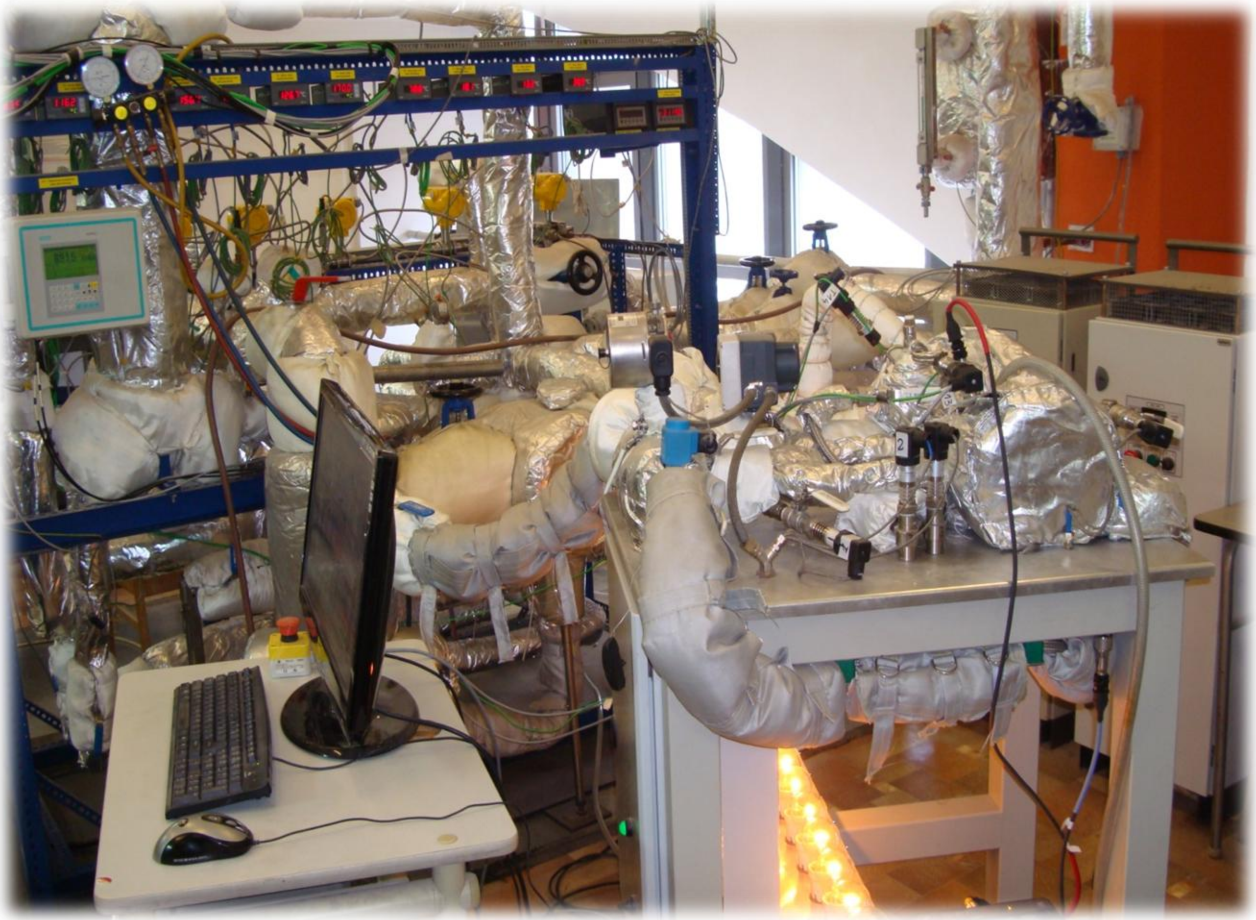

Fig. 2. The ORC system with a radial microturbine and a set of heaters in the test bench

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2. EXPERIMENTAL SETUP - investigated cycle

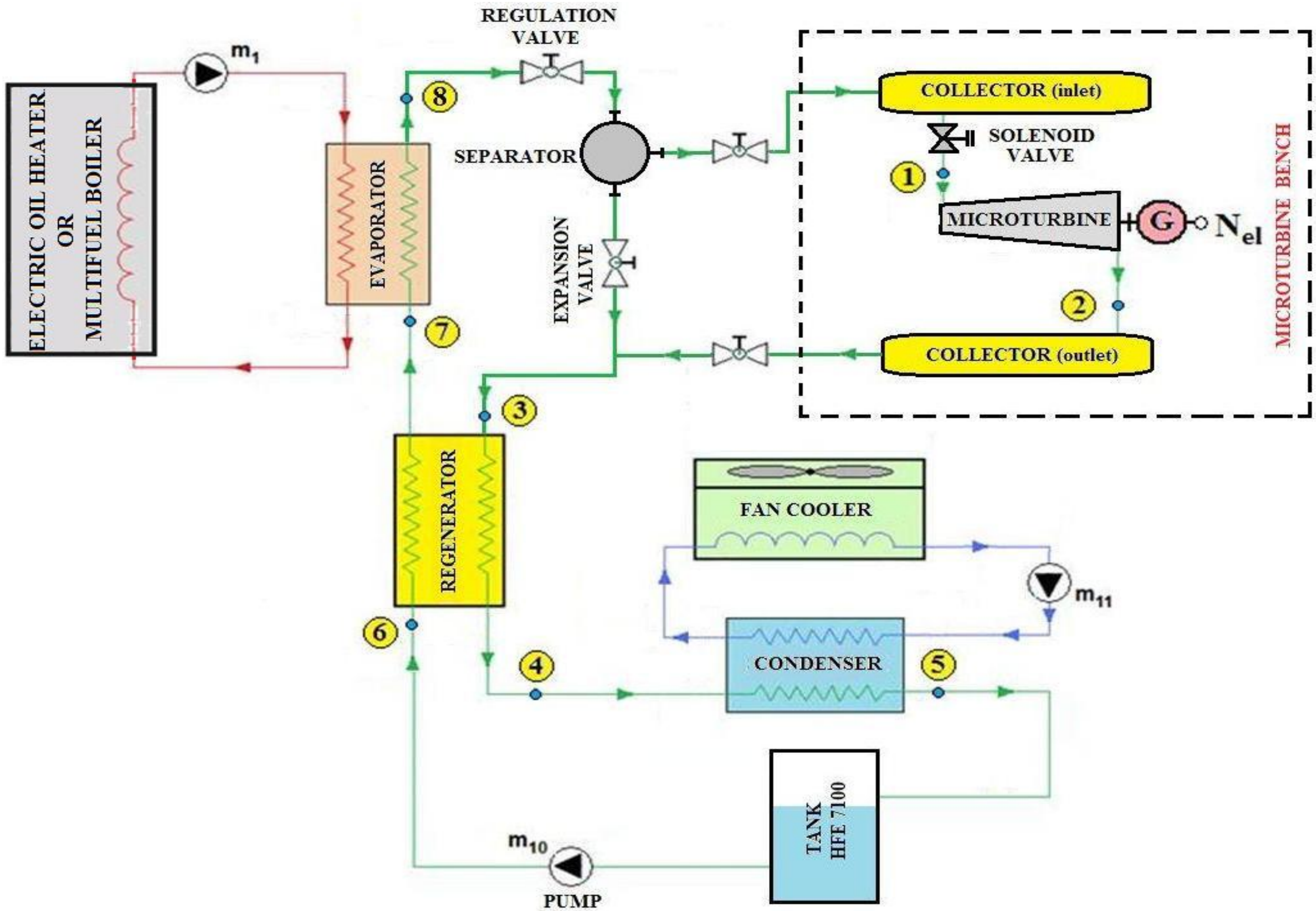

Fig. 3. Measurement scheme of the regenerative ORC with a microturbine

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2. EXPERIMENTAL SETUP - heating cycles

Fig. 4. Prototype of the electric flow heater for oil – power 2x24 kW_e

Fig. 5. Prototype of the multifuel boiler (1st generation) with a solid fuel reservoir (biomass-pellets) – power about 25 ÷ 30 kW_{th}

Fig. 6. Prototype of the multifuel boiler (2nd generation) – power about 30 ÷ 35 kW_{th}

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2. EXPERIMENTAL SETUP - radial microturbine

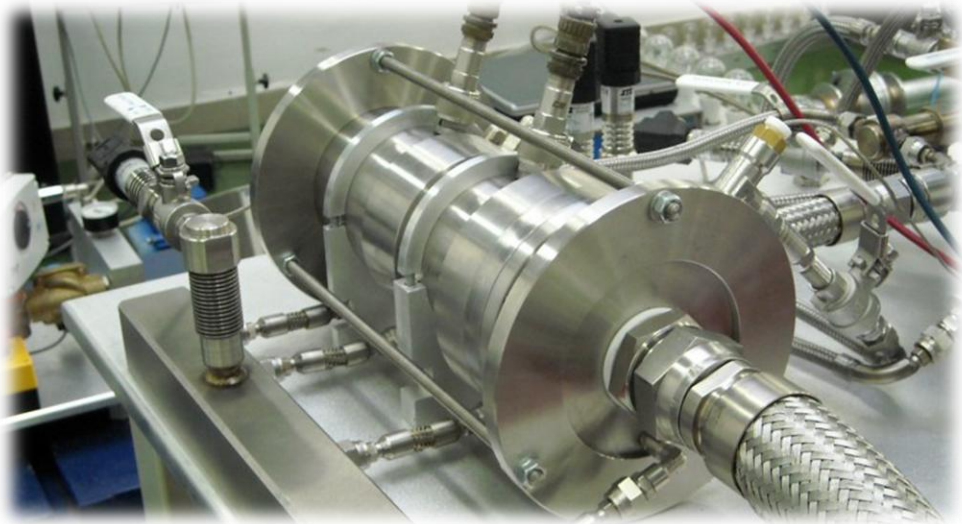
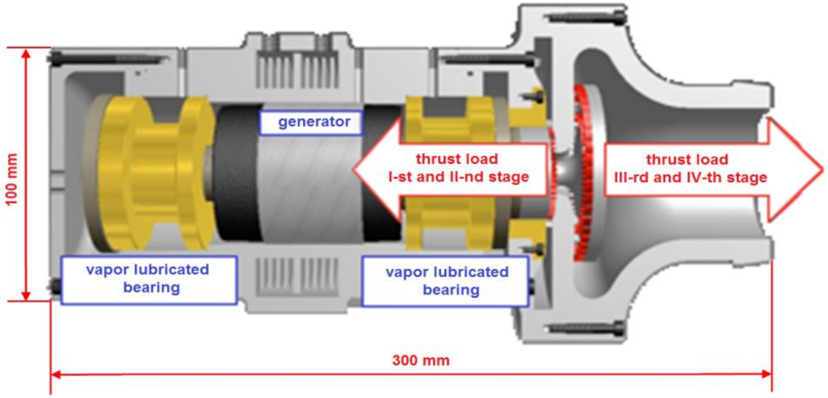


Fig. 7. Micro-turbogenerator equipped with four-stage radial turbine

Fig. 8. Rotor of the four-stage radial turbine

The main parameters:

- turbine power: 2.7 kW,
- isentropic efficiency: 84 %
- rotor speed: 24 000 rpm,
- mass flow rate: 170 g/s,
- pressure drop: 11 bar,
- working medium: HFE 7100,



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2. EXPERIMENTAL SETUP - cooling cycle

Fig. 9. Fan coolers – power 2x50 kW

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3. EXPERIMENTAL RESULTS

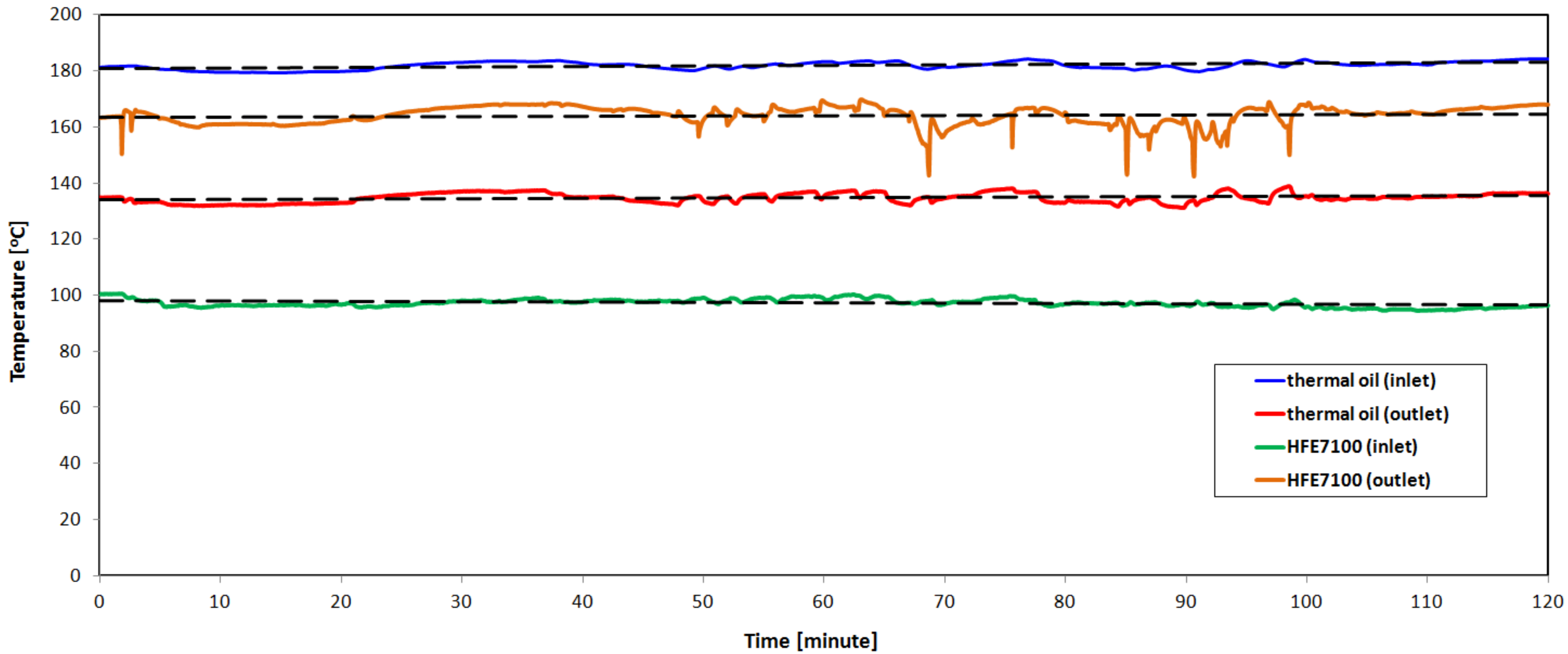

Fig. 10. The temperature of working medium (HFE7100) and thermal oil in the evaporator vs. time

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3. EXPERIMENTAL RESULTS

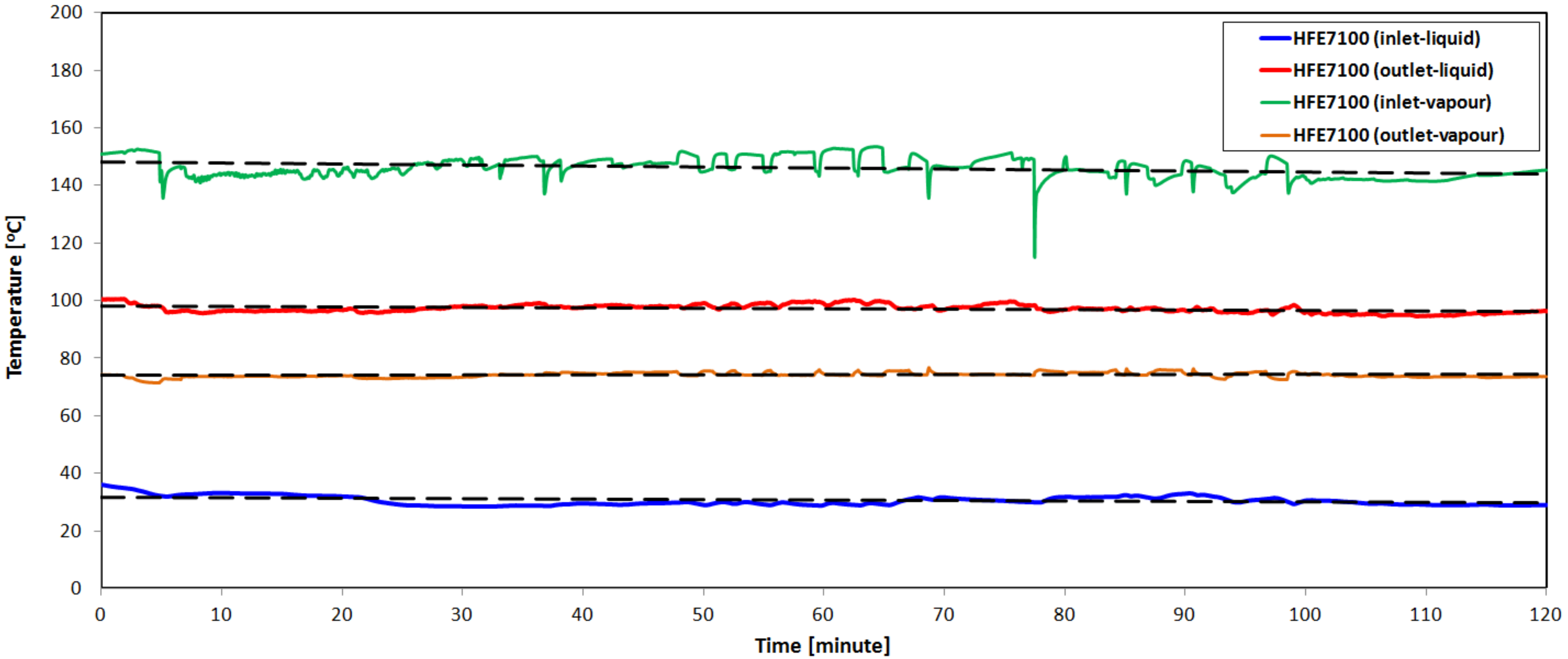

Fig. 11. The temperature of working medium (HFE7100) in the regenerator vs. time

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3. EXPERIMENTAL RESULTS

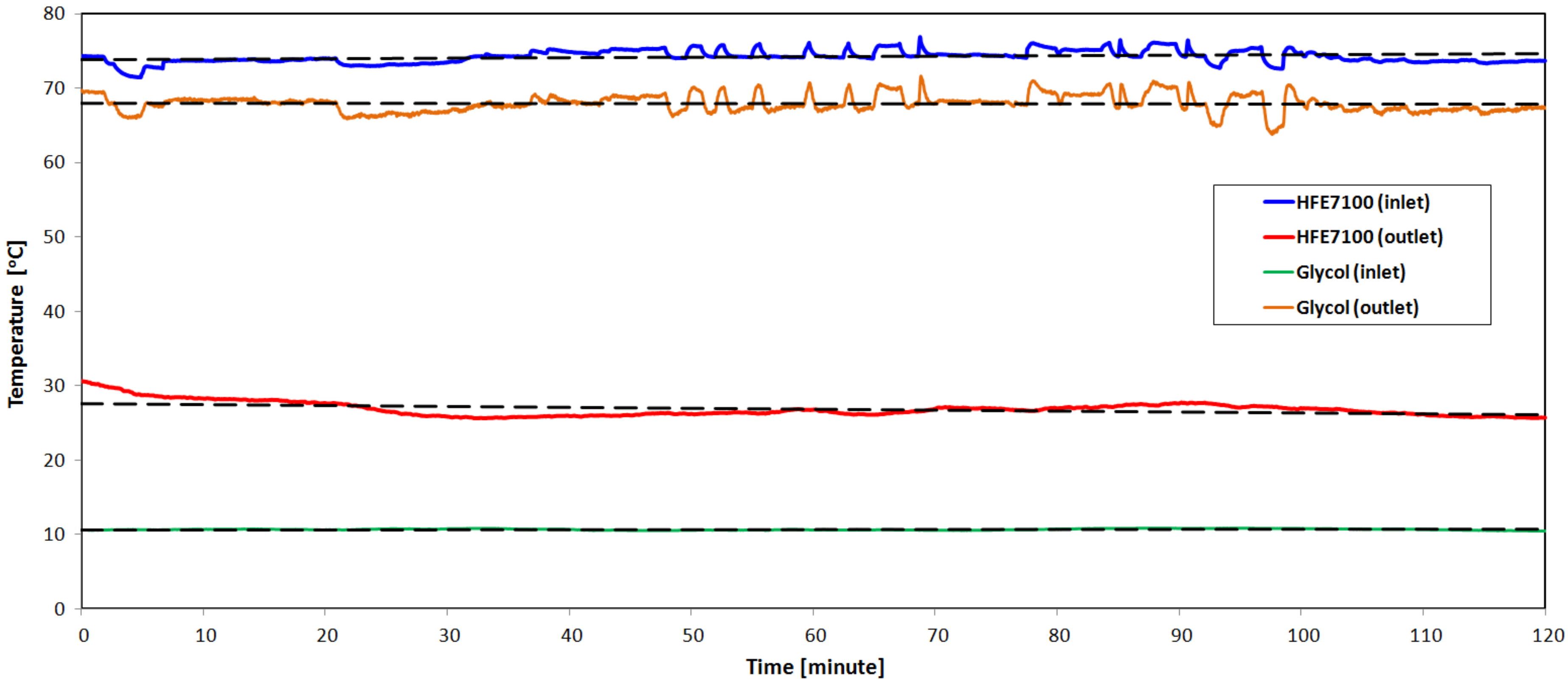

Fig. 12. The temperature of working medium (HFE7100) and glycol in the condenser vs. time

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3. EXPERIMENTAL RESULTS

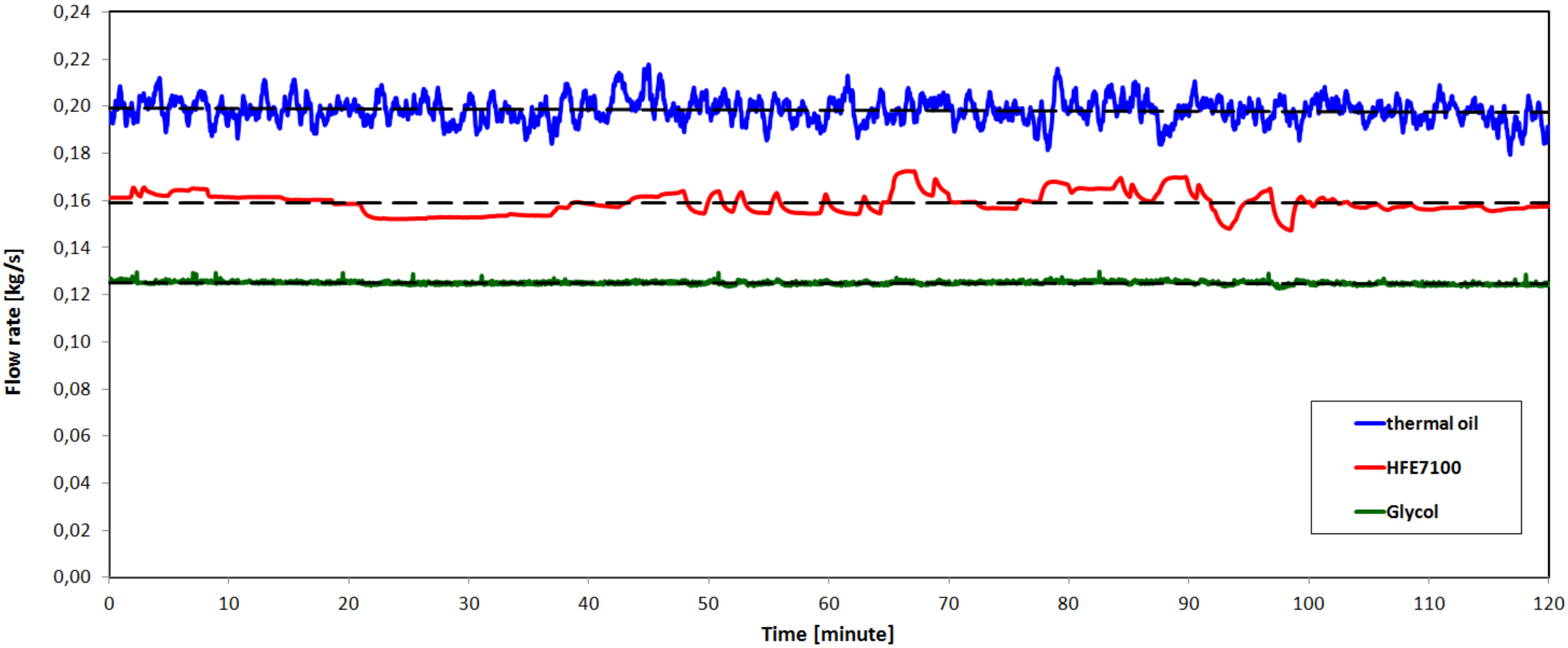

Fig. 13. The mass flow rate of working medium (HFE7100) vs. time (during microturbine operation)

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3. EXPERIMENTAL RESULTS

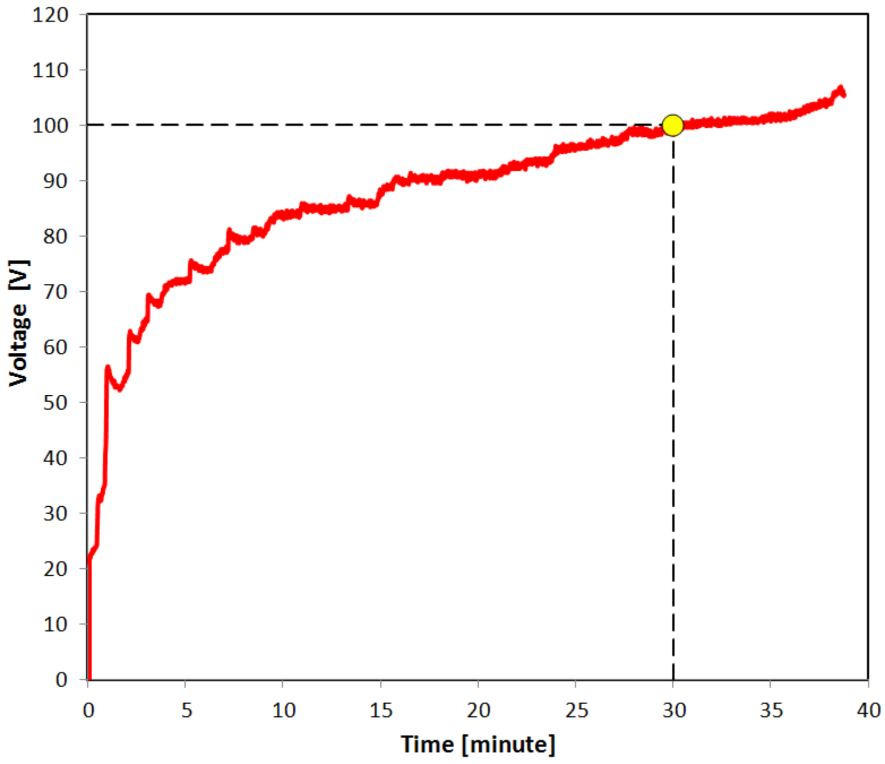

Fig. 14. Voltage generated of the radial microturbine vs. time

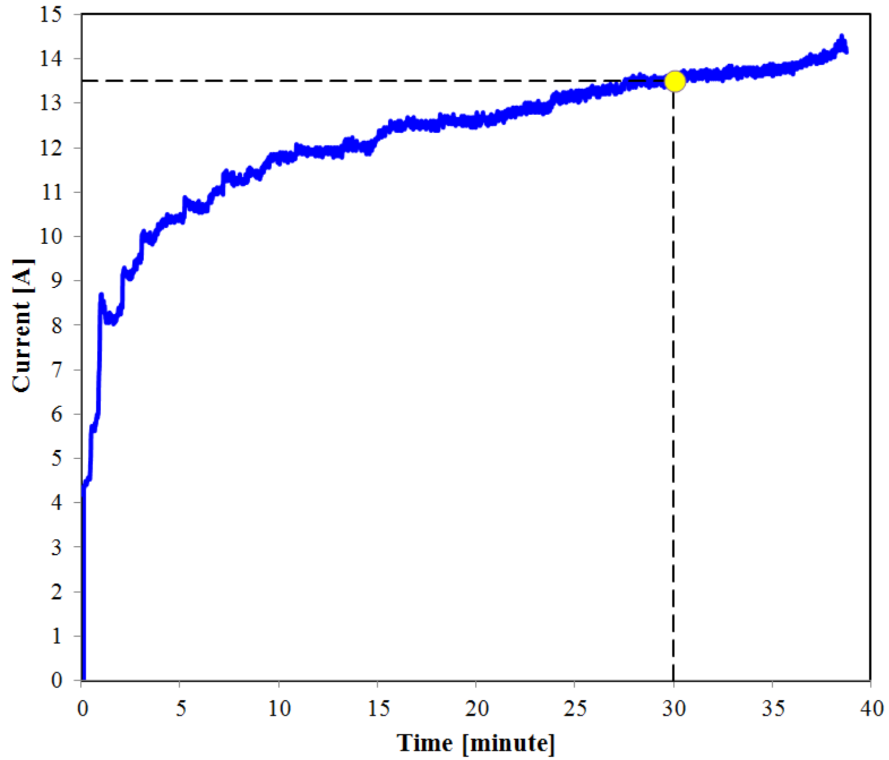

Fig. 15. Load current of the radial microturbine vs. time

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3. EXPERIMENTAL RESULTS

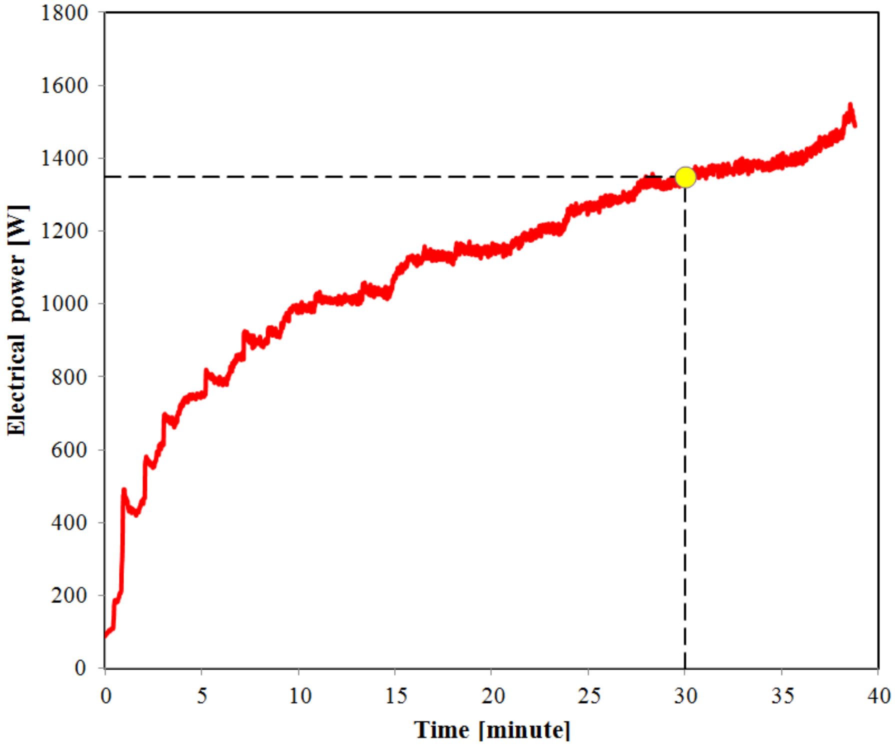

Fig. 16. Electric power curve registered during microturbine operation

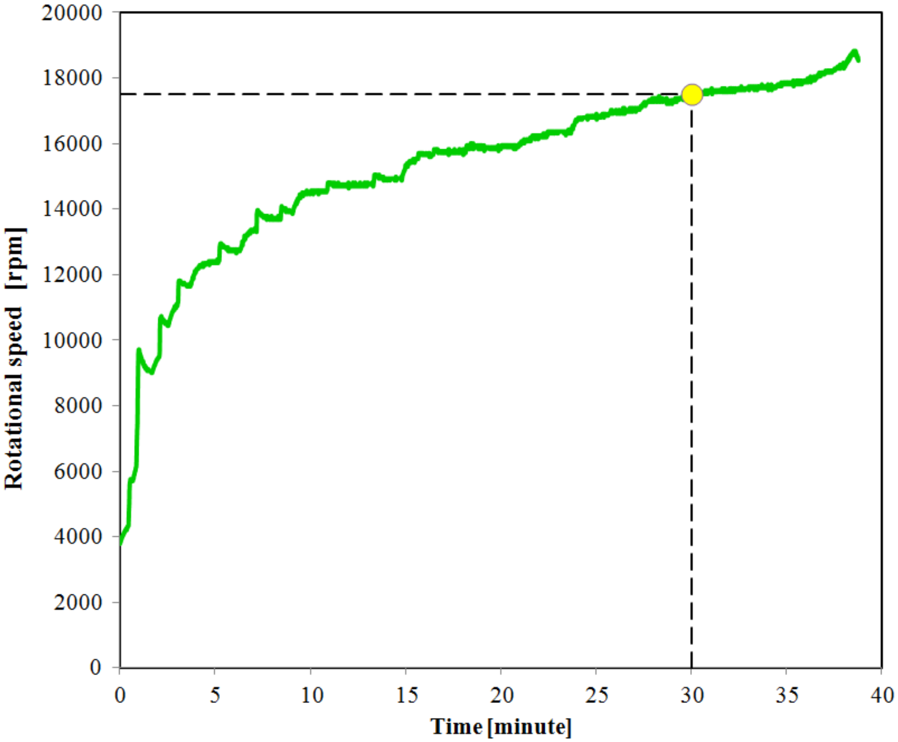

Fig. 17. Microturbine rotational speed registered during the measurement

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3. EXPERIMENTAL RESULTS

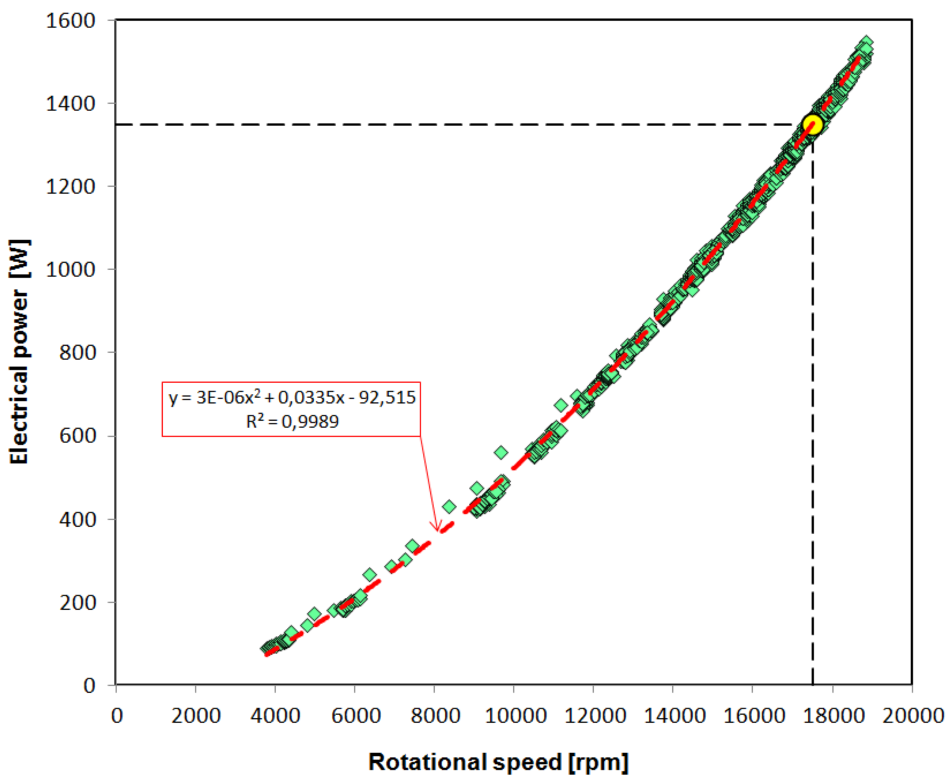

Fig. 18. Electric power generated by the microturbine vs. rotational speed

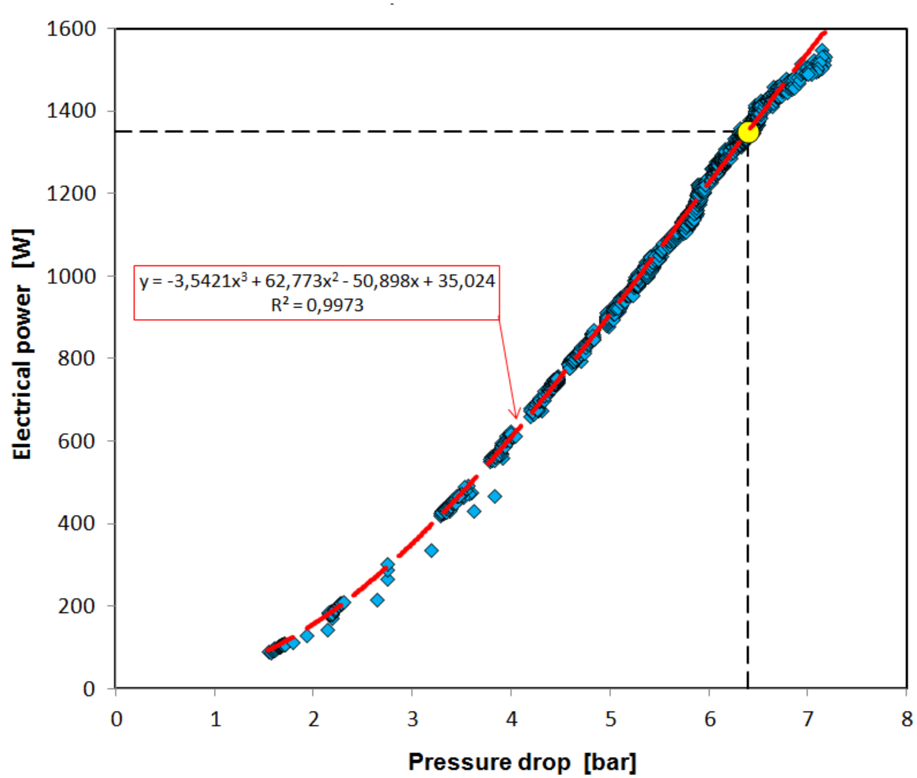

Fig. 19. Electric power generated by the microturbine vs. pressure drop

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3. EXPERIMENTAL RESULTS

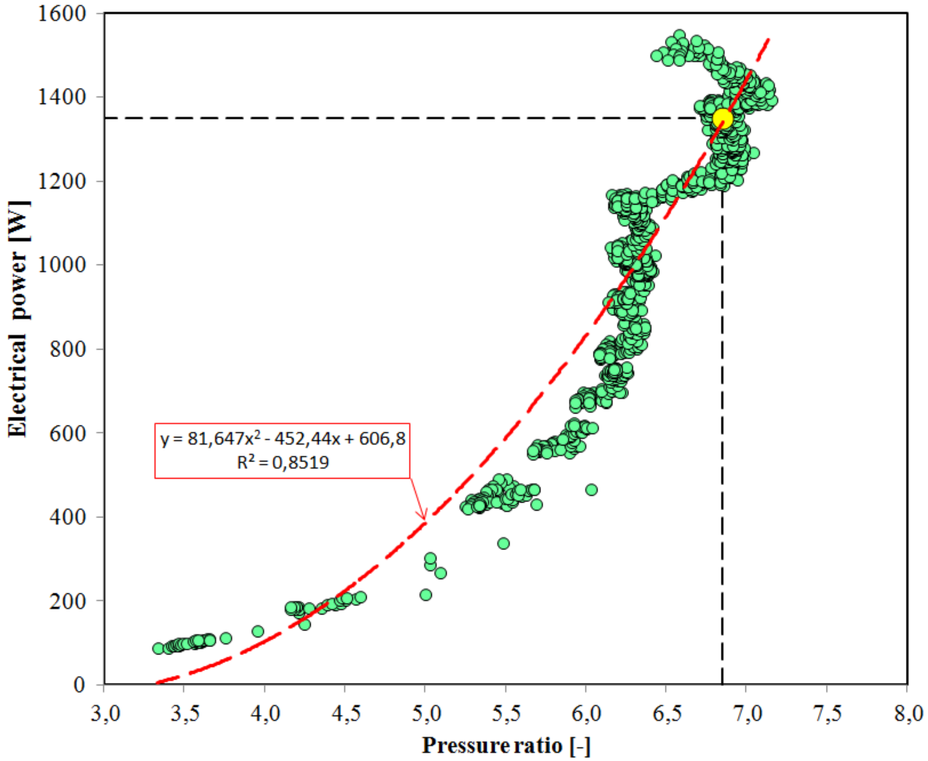

Fig. 20. Electric power generated by the microturbine vs. pressure ratio

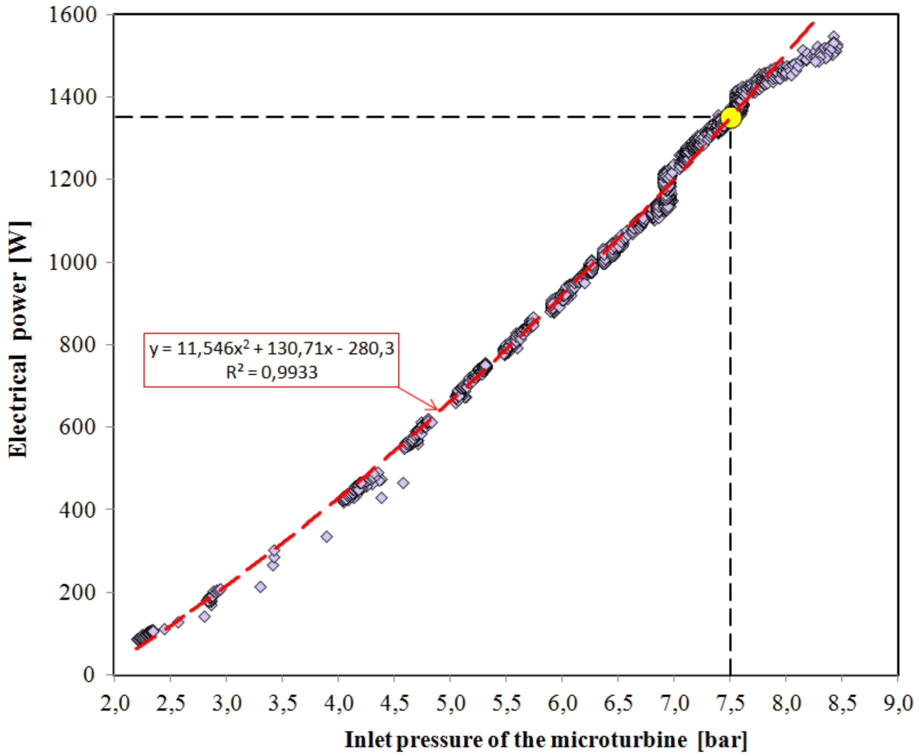

Fig. 21. Electric power generated by the microturbine vs. inlet pressure

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3. EXPERIMENTAL RESULTS

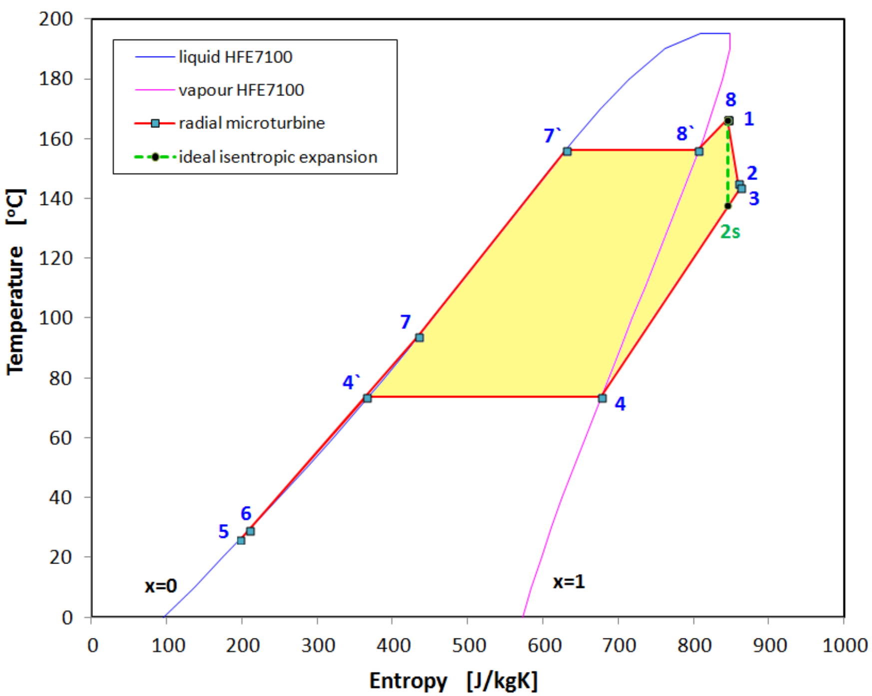

Fig. 22. T-s diagram ORC system with radial microturbine

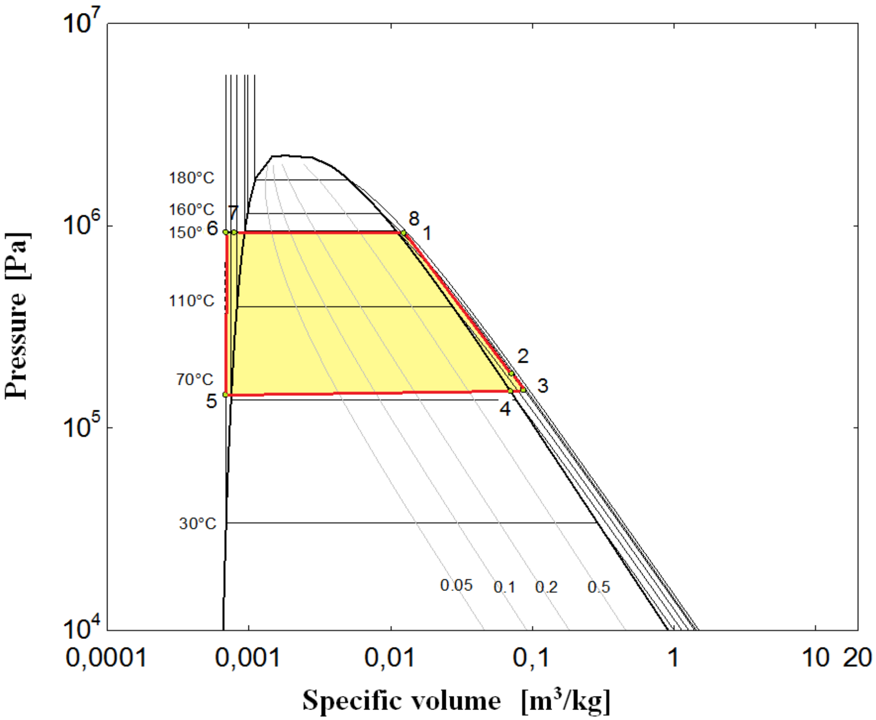

Fig. 23. P-v diagram ORC system with radial microturbine

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3. EXPERIMENTAL RESULTS

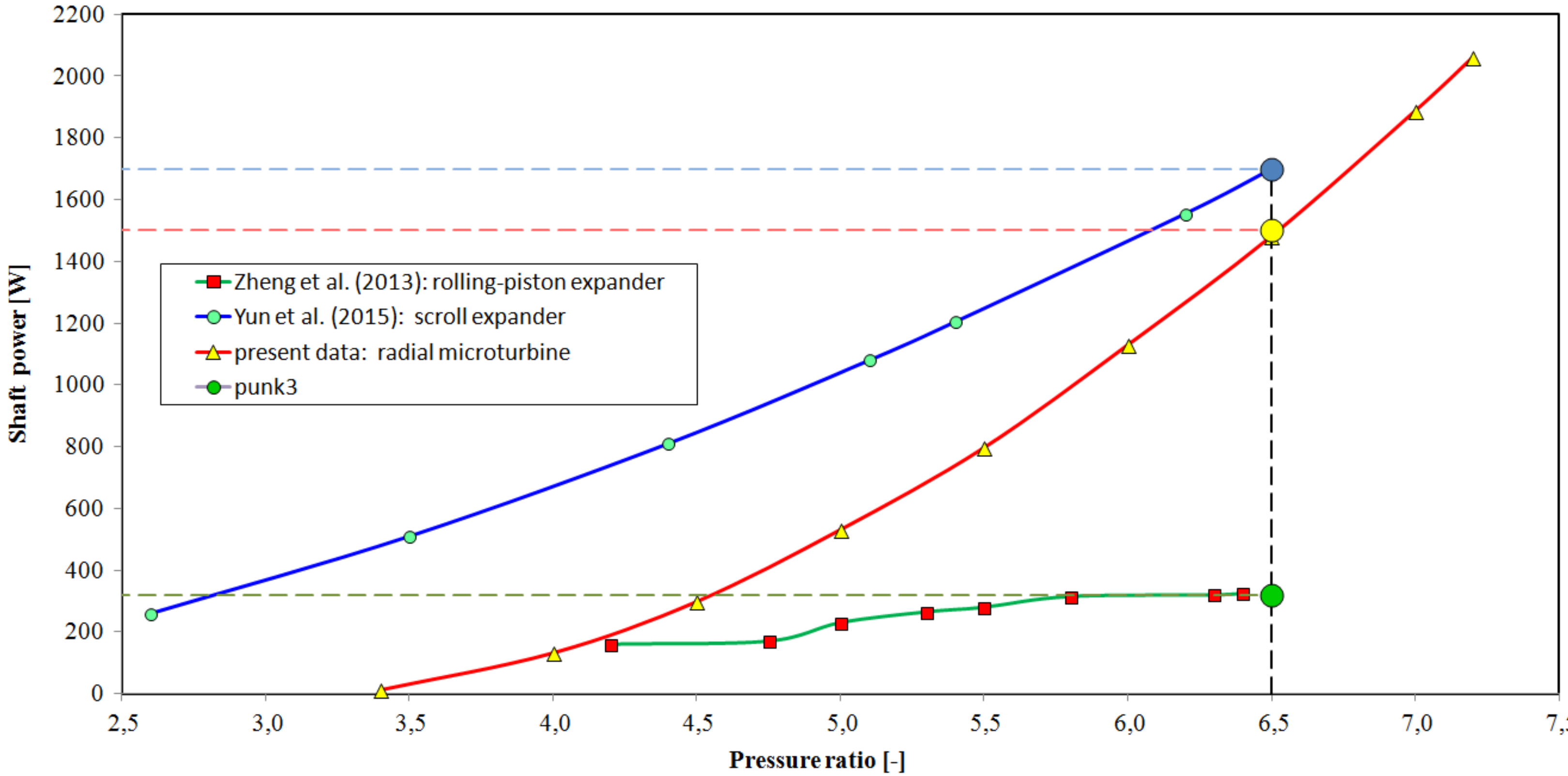

Fig. 24. Comparison of the power generated by different expanders and radial microturbine vs pressure ratio

Zheng N., Zhao L., Wang X.D., Tan Y.T.: Experimental verification of a rolling-piston expander that applied for low-temperature Organic Rankine Cycle, 2013, *Applied Energy,* 112, p. 1265-1274

Yun, E., Kim, D., Yoon, S. Y., Kim, K. Ch., 2015, Experimental investigation of an organic Rankine cycle with multiple expanders used in parallel, *Applied Energy,* 145: p. 246-254.

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Short movie

The radial microturbine operating in the ORC system installed on the test bench located at the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences in Gdańsk.

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4. CONCLUSION

Parameters	Value
Inlet temperature of HFE7100 in the microturbine	166.5 °C
Outlet temperature of HFE7100 in the microturbine	145.0 °C
Inlet pressure of HFE7100 in the microturbine	9.21 bar
Outlet pressure of HFE7100 in the microturbine	1.86 bar
Mass flow rate of the HFE7100	155 g/s
Electrical power generated by the microturbine	1551 W

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4. CONCLUSION

Efficiency	Relation	Results
Carnot	$\eta_C = 1 - \frac{T_{\min}}{T_{\max}}$	31.98%
isentropic of the microturbine	$\eta_{s,ex} = \frac{h_1 - h_2}{h_1 - h_{2s}}$	70.61%
thermal of the ORC system	$\eta_{ORC} = \frac{(h_1 - h_2) - (h_6 - h_5)}{h_8 - h_6}$	5.95%
exergetic	$\eta_{exerg} = \frac{\eta_{ORC}}{\eta_C}$	18.55%

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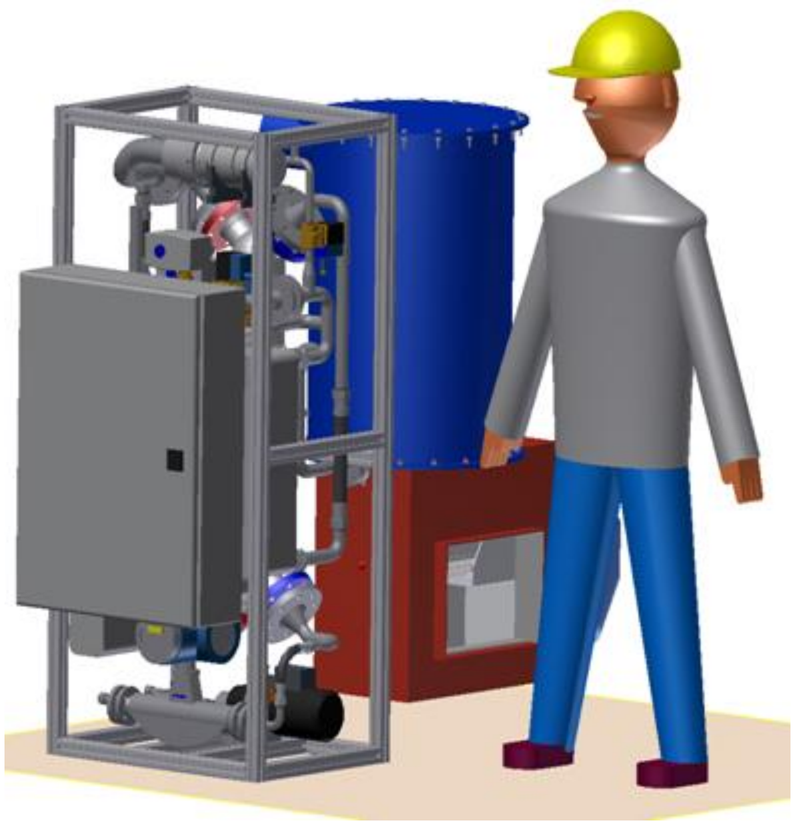
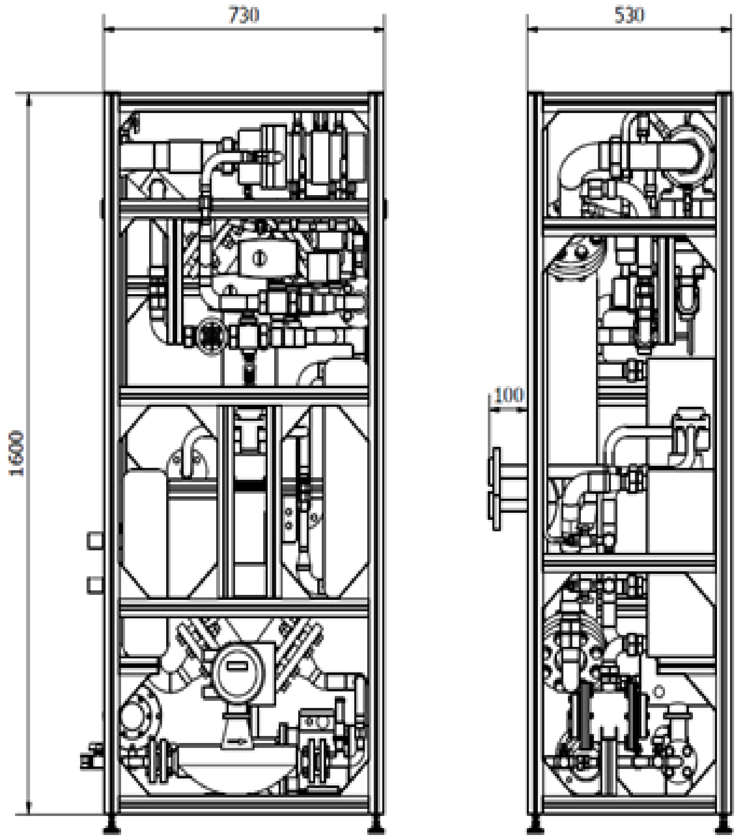
Two years earlier (ASME ORC 2013) !





Construction design of a micro power plant – view from the cogeneration module – comparison with a human

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Now (ASME ORC 2015) – more information on the session 14, Wednesday at 8:40

G. Zywica, J. Kicinski, T. Z. Kaczmarczyk, E. Ihnatowicz, T. Turzynski, S. Bykuć.

PROTOTYPE OF THE DOMESTIC CHP ORC SYSTEM: CONSTRUCTION AND EXPERIMENTAL RESEARCH.

CAD 3D model

Complete prototype in the laboratory

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Thank you for your attention

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