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EXPERIMENTAL INVESTIGATION OF THE ORC SYSTEM IN A COGENERATIVE DOMESTIC POWER PLANT WITH A MICROTURBINE AND AN EXPANSION VALVE

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Outline of presentation

1. Introduction
2. Experimental set up
   - investigated cycles
   - heating cycles
   - microturbines
3. Experimental results
4. Conclusions

1. INTRODUCTION

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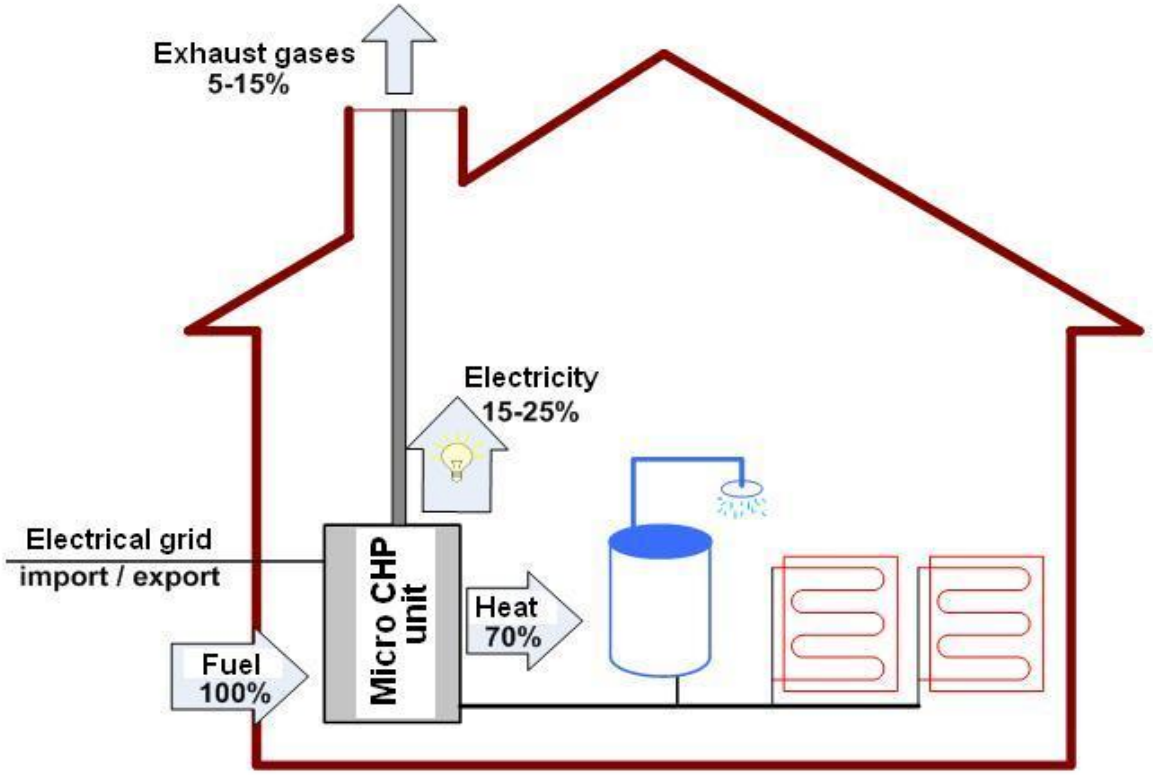
In order to meet the directives and trends indicated by the European Union, concerning the systems using renewable sources of energy, the idea of a home micro-power plant is worked up in the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences in Gdańsk.



A general scheme of a domestic micro combined heat and power unit.

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Micro-Cogeneration Plant

is a system used in combined heat and power (CHP) on small-scale production for individual and industrial needs.

Reason of our interest?

- significant increase of fuel energy efficiency in combined heat and power production when compared to conventional power plants,
- necessity to increase the share of renewable resources in the fuel-energetic balance,
- improvement of ecological and energetic safety obtained through:
  - decentralization of power production,
  - diversification of energy sources,
  - use of the local energy sources,
- electric energy production savings.

Advantages of ORC systems:

- possibility to use low-temperature heat sources and thus to use renewable energy sources,
- possibility to use biogas and lignocelluloses biomass thanks to a multi-fuel boiler,
- possibility to use secondary waste heat,
- module-based construction - ease of adjustment to the required power range,
- compatibility with gas turbines, fuel engines and fuel cells stacks, cold production systems.

2. EXPERIMENTAL SET UP

The co-generative micro-power plant
with the HFE 7100 (solvent) 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 kW,
- electric output: 2 - 3 kW
- the pressure at turbine inlet: 12 bar,
- the temperature at turbine inlet: 160^{o}C,

The reasons of selecting the fluid HFE 7100 as a working medium for the CHP ORC system are:

- Good efficiency for the specified temperature of the heat source and of the water produced for heating purposes,
- The lowest pressure in the system is above the atmospheric pressure – no air leakage to the system,
- The fluid chosen is a “dry” fluid – no problem with erosion of a turbine blades after expansion,
- The fluid is non-flammable, low toxic and chemically and thermally stable,
- Zero ozone depletion potential.

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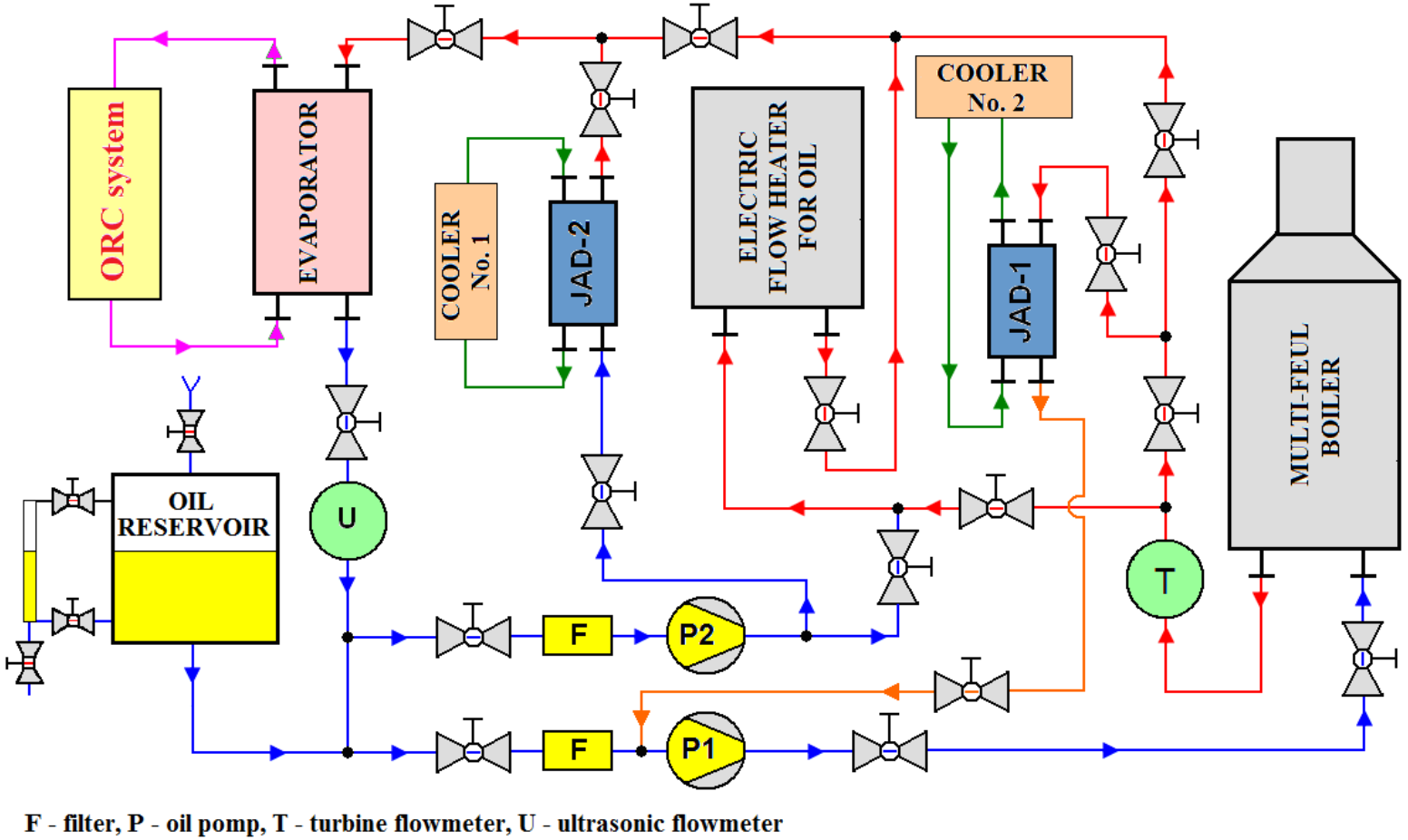
The ORC system with a microturbine and a set of heaters in the test bench in the Institute of Fluid-Flow Machinery of the Polish Academy of Science in Gdańsk.



F - filter, P - oil pomp, T - turbine flowmeter, U - ultrasonic flowmeter

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

Investigated cycles

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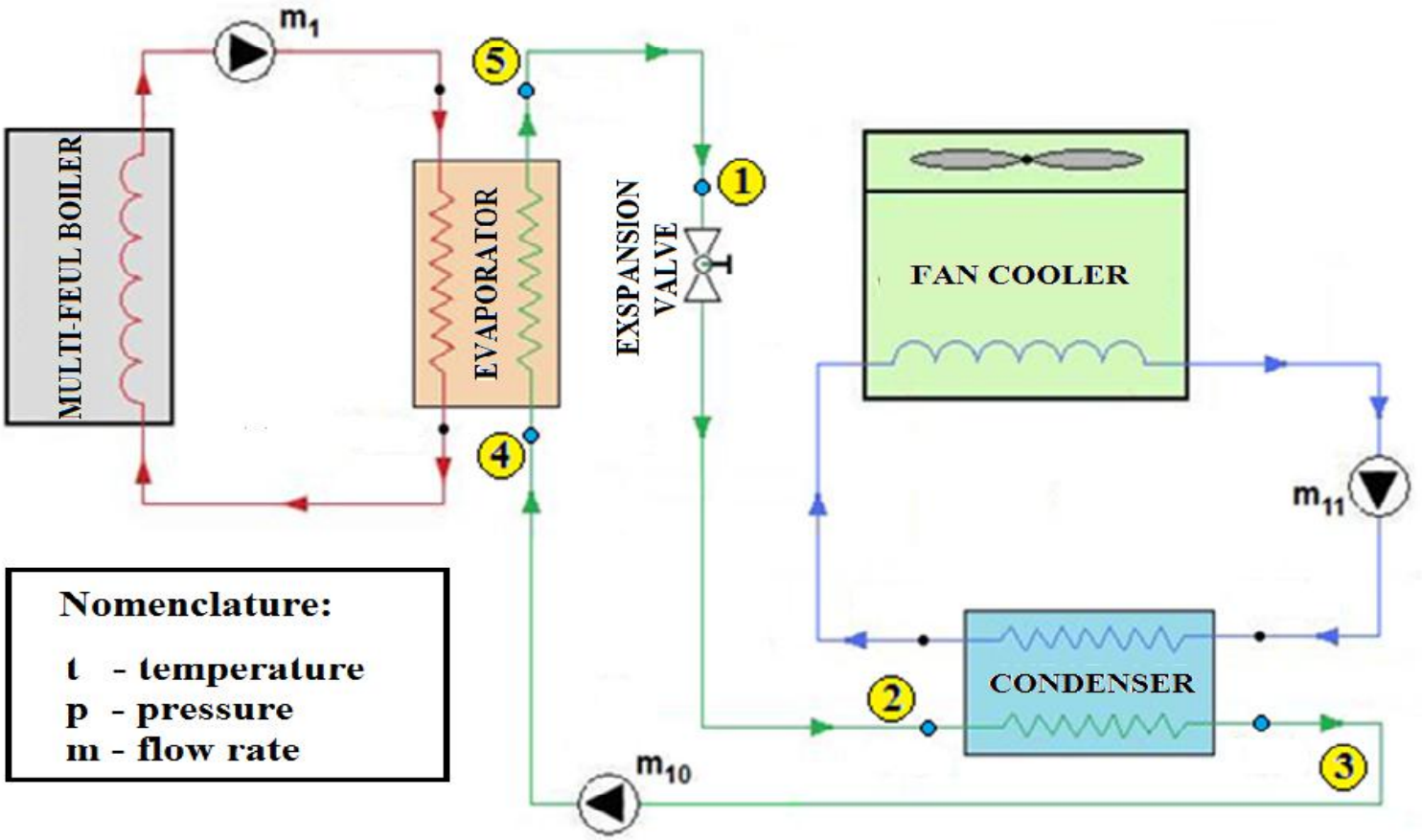

Measurement scheme of the ORC non-regeneration cycle.

Investigated cycles

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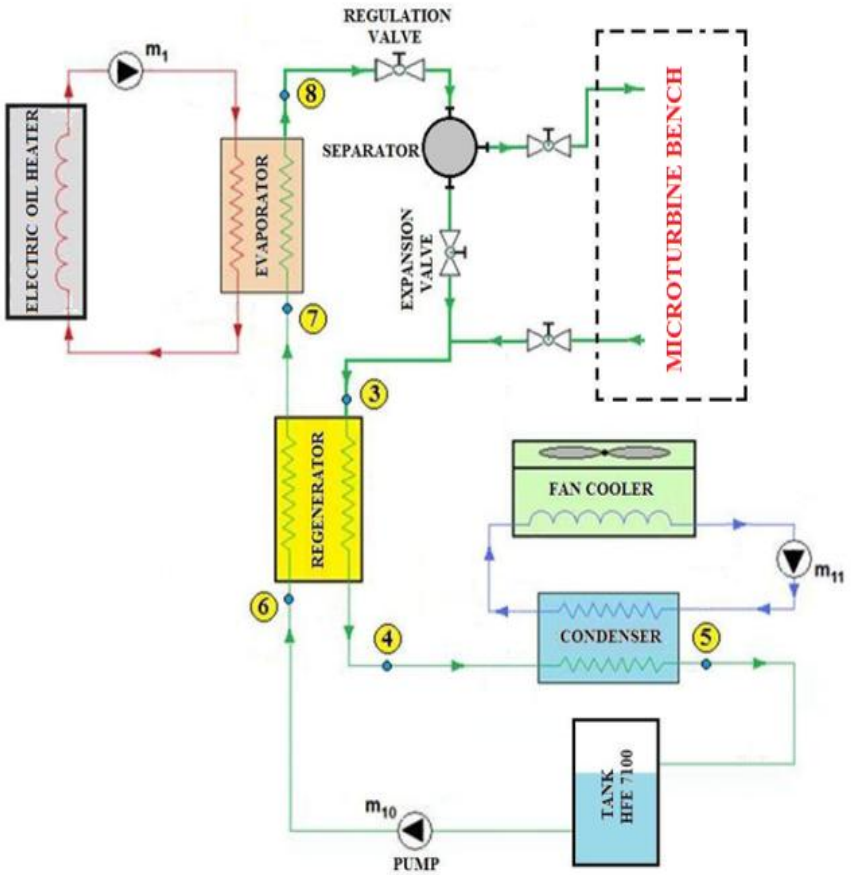
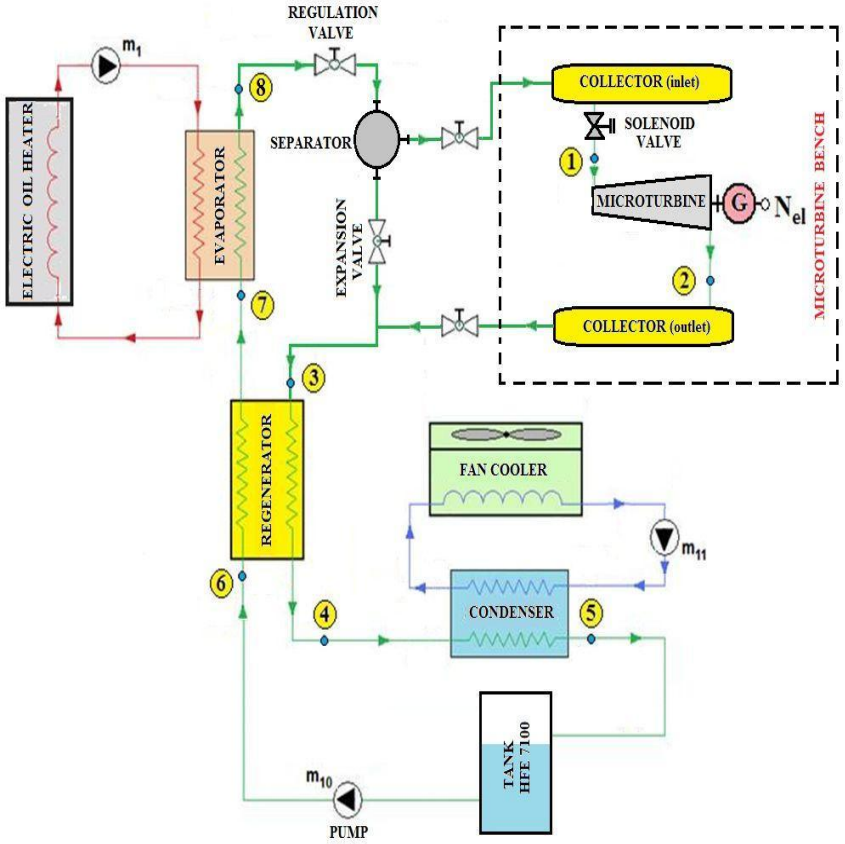


Measurement scheme of the regenerative ORC with an expansion valve.



Measurement scheme of the ORC regeneration cycle and microturbine.

Heating cycle

Prototype of electric flow heater for oil.

Prototype of multi-fuel boiler with a solid fuel reservoir (biomass-pellets).

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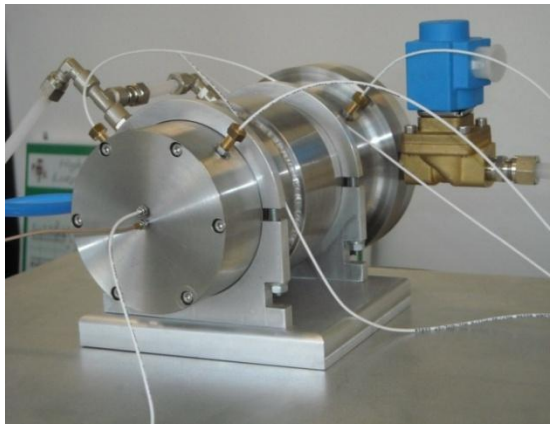
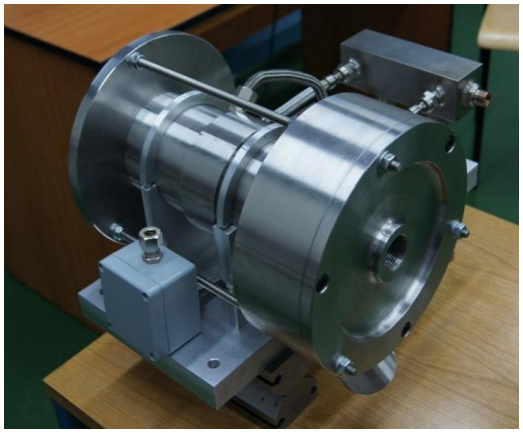
Microturbine:

- radial turbine (high-speed)



Parameters:

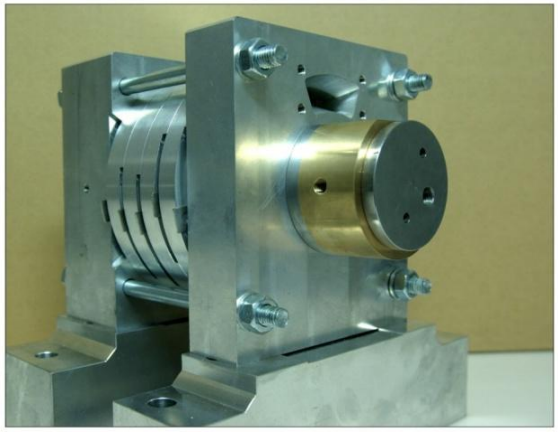
- electrical power: 2.7 kW,
- pressure inlet: 12 bar,
- rotor speed: 24 000 rpm,
- working medium: HFE 7100,



Parameters:

- electrical power: 3.3 kW,
- pressure inlet: 11 bar,
- rotor speed: 36 000 rpm,
- working medium: HFE 7100,

- axial turbine (low-speed)

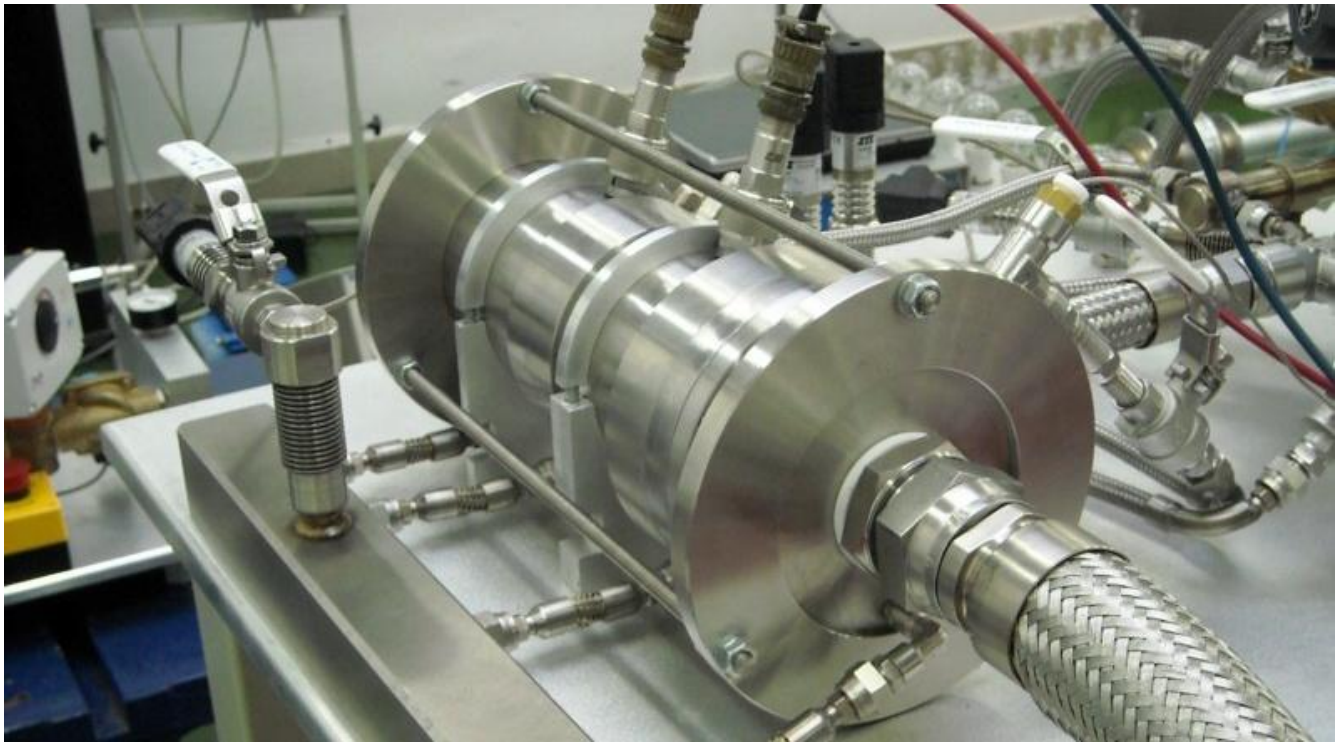


Parameters:

- electrical power: 3.0 kW,
- pressure inlet: 12 bar,
- rotor speed: 8 000 rpm,
- working medium: HFE 7100,

Radial microturbine:

Micro-turbogenerator equipped with four stage radial turbine.



The main parameters:

- **turbine power: 2.7 kW,**
- **isentropic efficiency: 70 %**
- **rotor speed: 24 000 rpm,**
- **mass flow rate: 170 g/s,**
- **working medium: HFE 7100,**

Axial microturbine:

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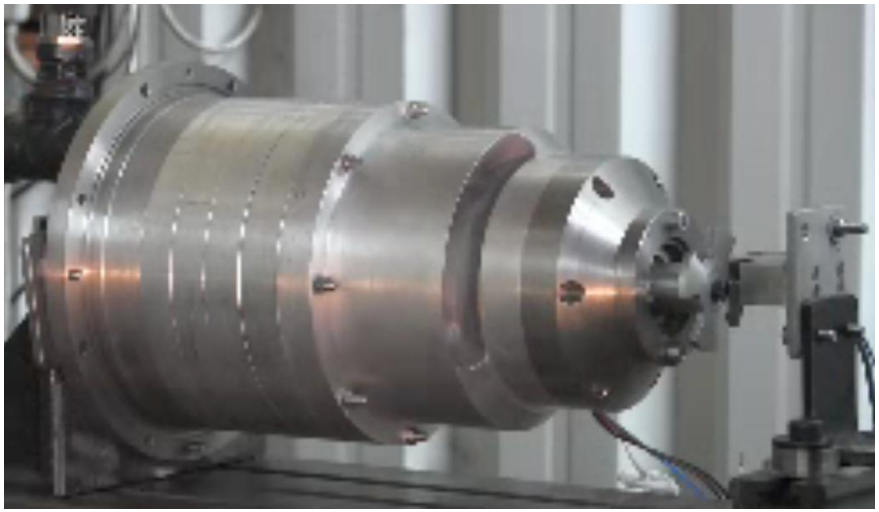

Microturbine coupled with the electric generator.

The main parameters:

- turbine power: 3.0 kW,
- stage diameter: 100 mm,
- blade height: 10 mm,
- rotor speed: 8 000 rpm,
- working medium: HFE 7100.

Shrouded rotor of a axial turbine.

Pumps working with medium (HFE 7100)

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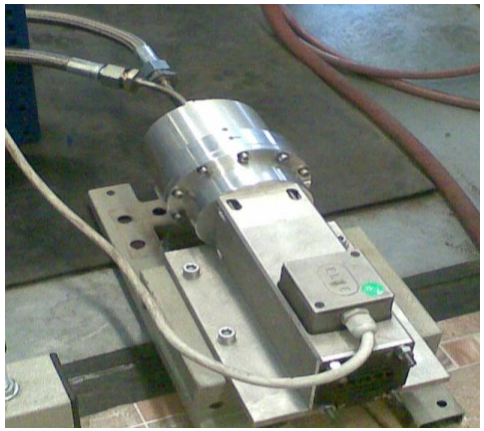
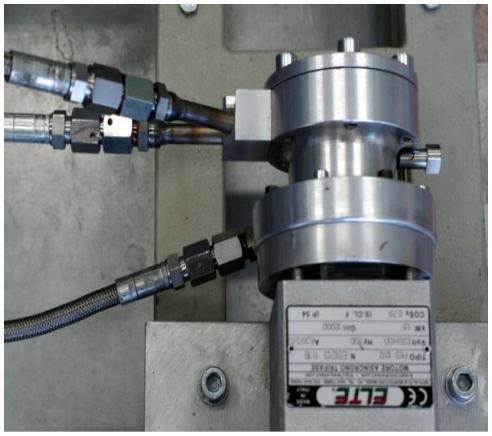


Prototype pitot tube pump.



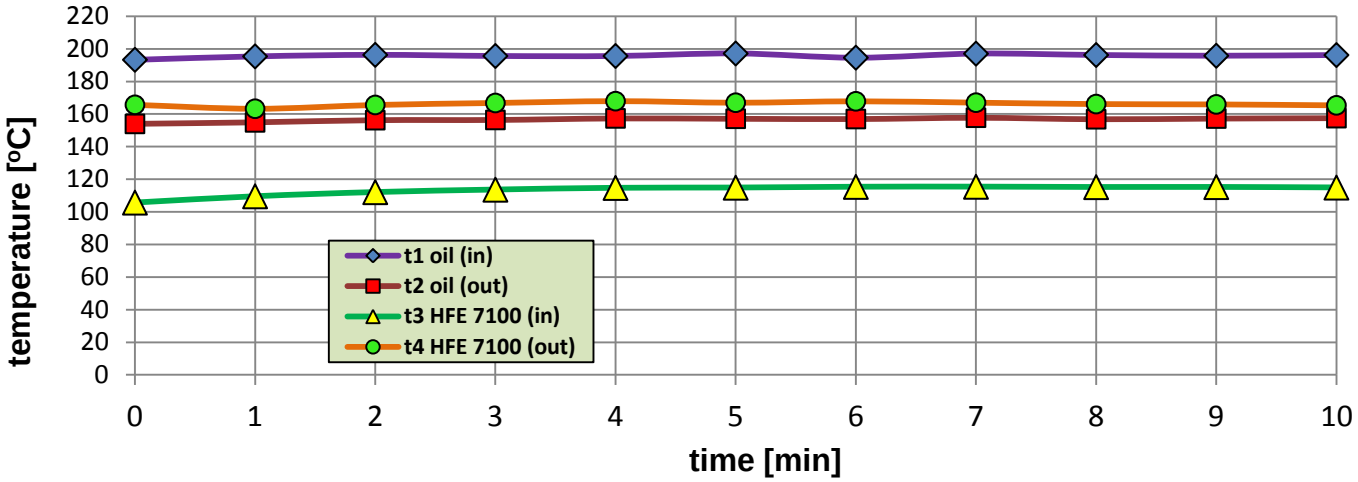
Prototype peripheral pump.

Commercial gear pump

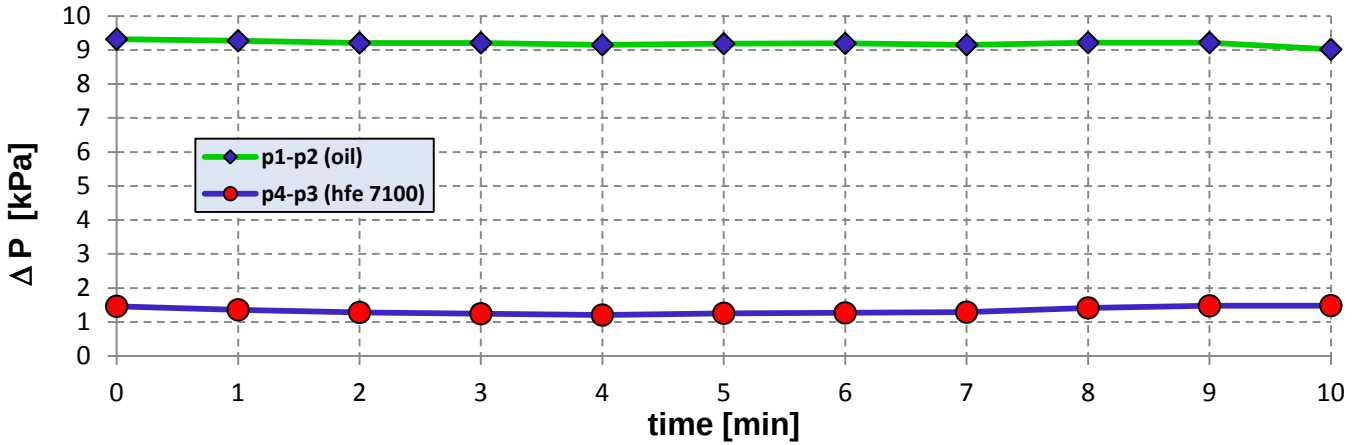
Commercial peripheral

Commercial gear pump

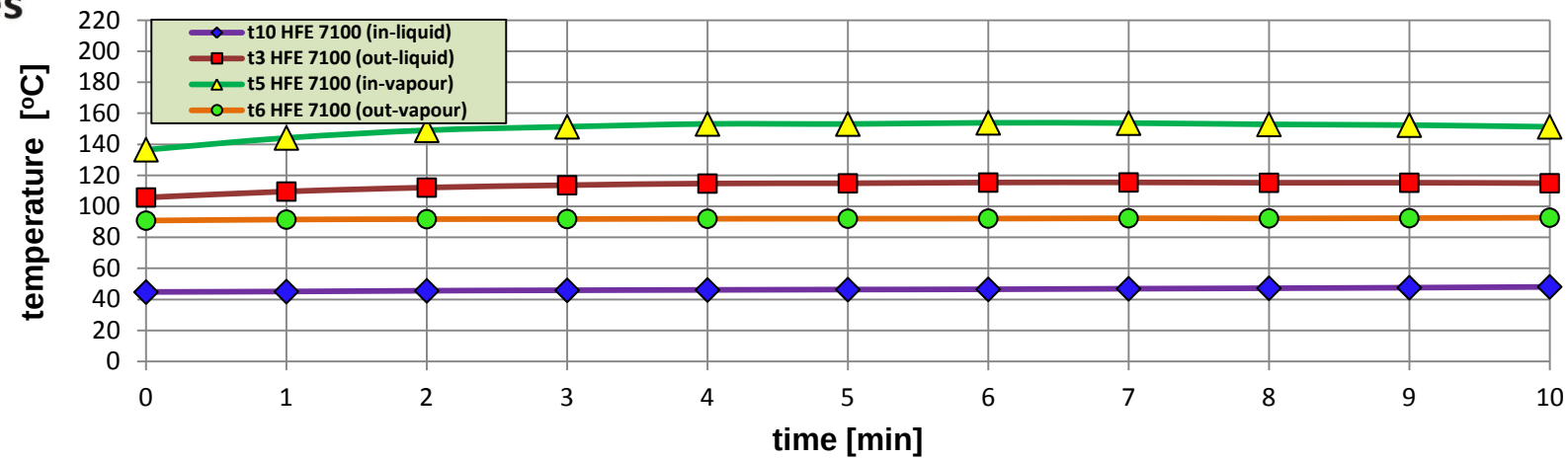
3. Experimental results



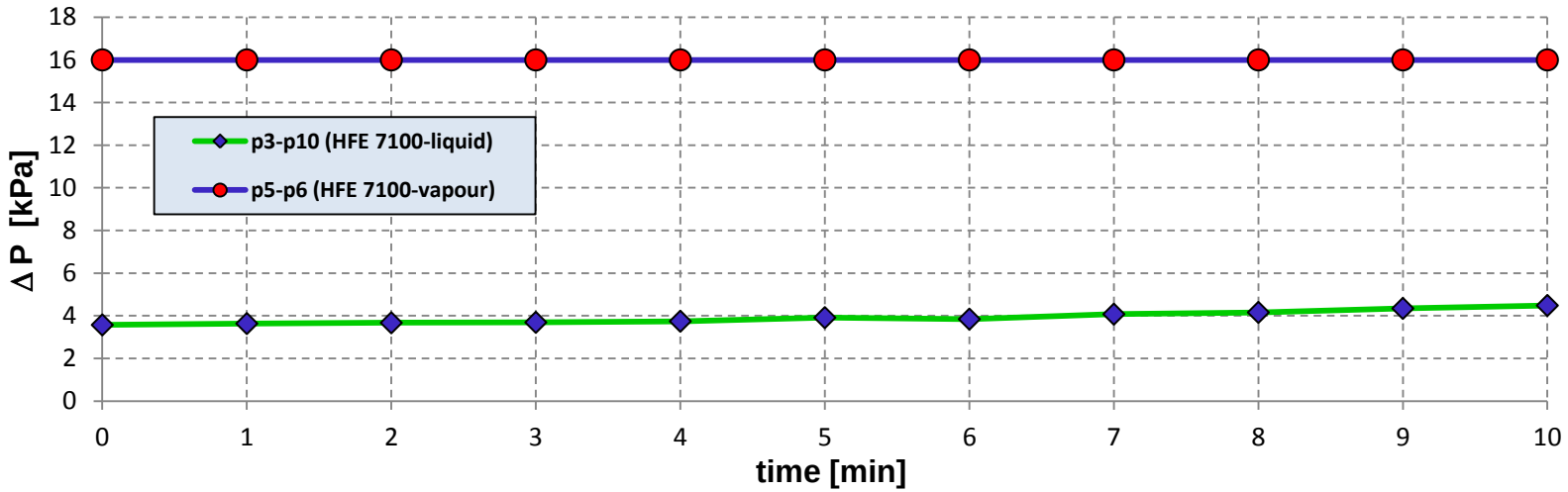
HFE7100 and thermal oil temperature versus time in the evaporator – temperature stability (gear pump).



HFE 7100 and thermal oil pressure drop versus time in the evaporator (gear pump).



Liquid and vapour HFE 7100 temperature versus time in the regenerator – temperature stability (gear pump).



Liquid and vapour HFE7100 pressure drop versus time in the regenerator (gear pump).

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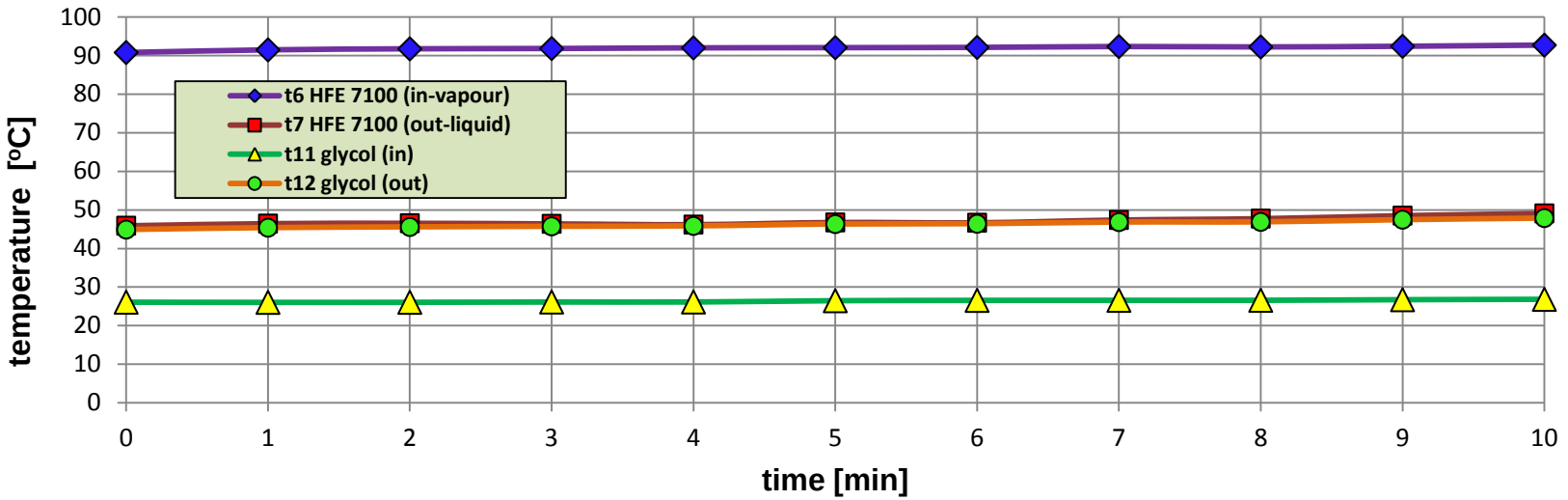
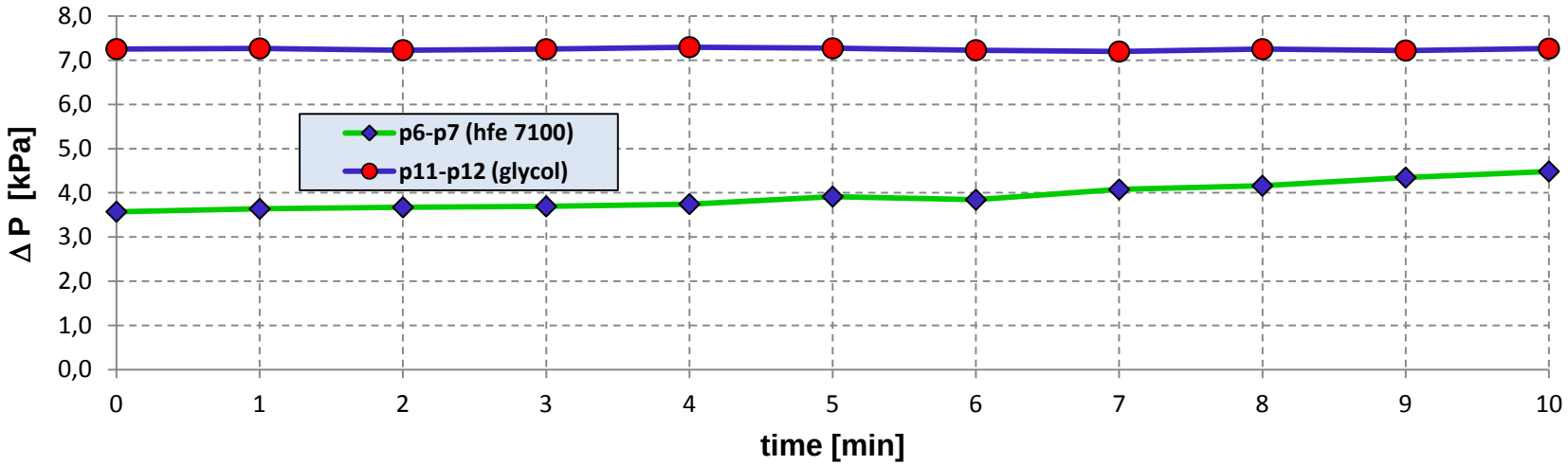


HFE7100 and glycol temperature versus time in the condenser - temperature stability (gear pump).



HFE 7100 and thermal oil pressure drop versus time in the condenser (gear pump).

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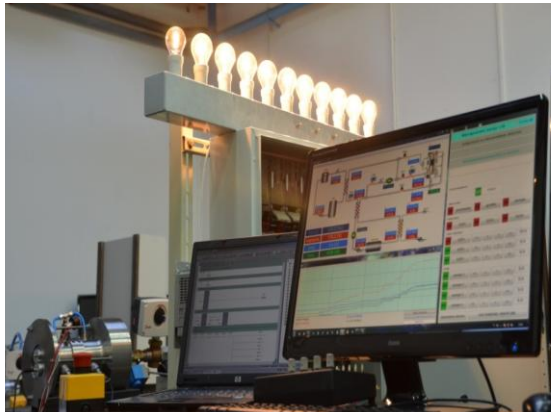

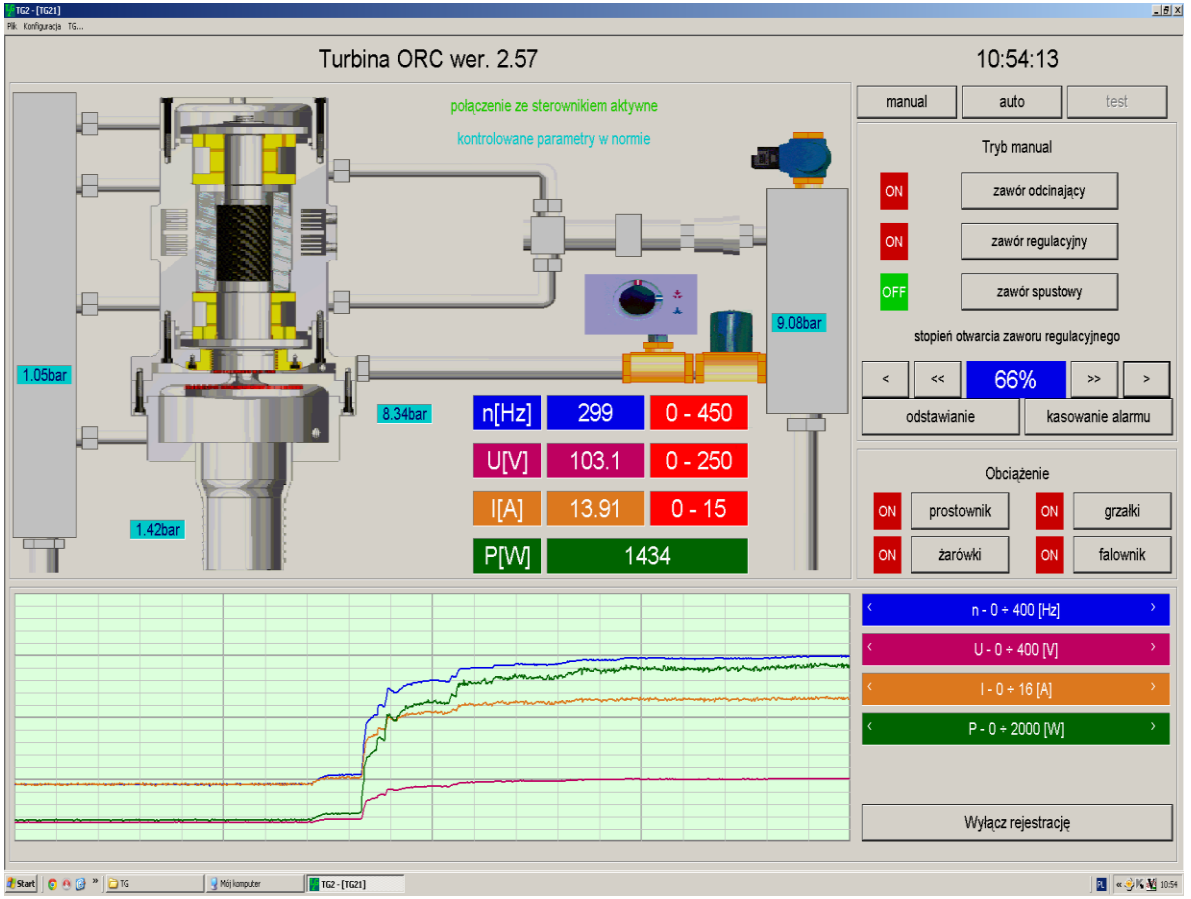

Rotational speed and power generated by the microturbine in the ORC system with a gear pump.

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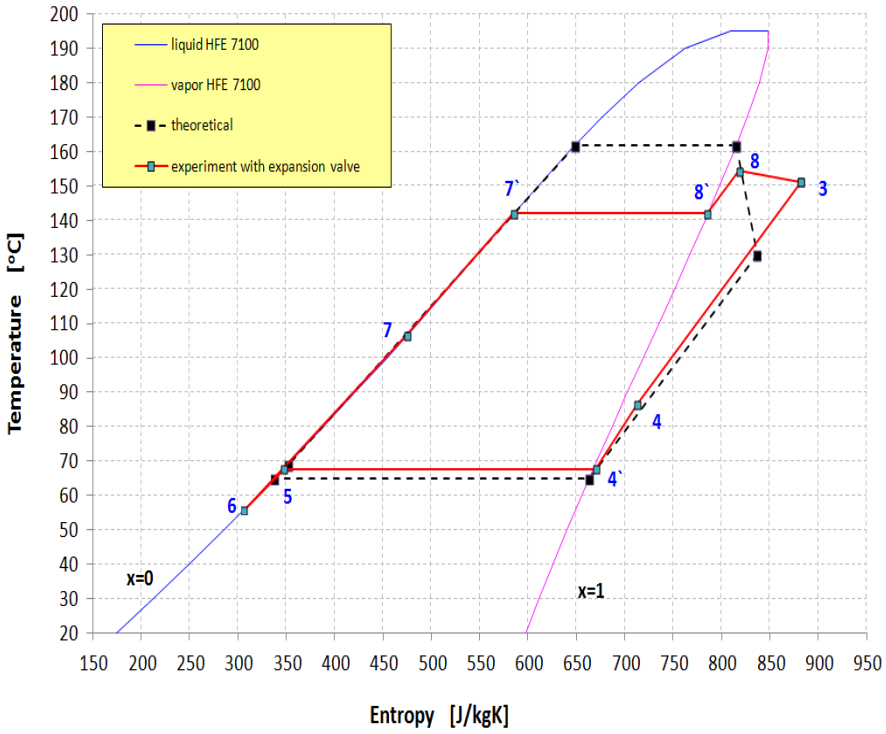
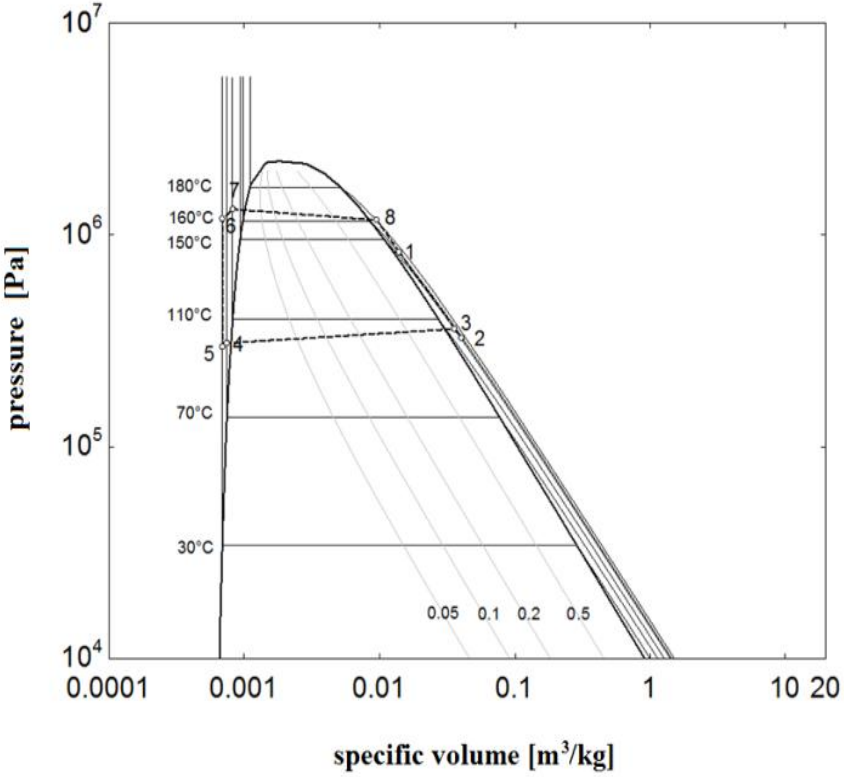


The examined ORC regeneration cycle with the gear pump in a T-s coordinate system.



P-v diagram of the regenerative ORC with a microturbine and a gear pump.

4. Conclusions

The design basis includes the following physicochemical parameters of HFE 7100 (working medium) at the inlet to the microturbine:

- temperature – 160 °C
- pressure inlet – 12 bar
- mass flow rate – 170 g/s

Compliance with these conditions is essential for the regular work of the turbine and reaching the required efficiency and electric power level (about 2 – 3 kW) by an ORC system.

The measurements performed in the test bench for ORC with regeneration and a gear pump allowed to obtain the following physicochemical parameters of HFE 7100:

- temperature inlet: 165 °C
- pressure inlet: 10 bar
- pressure behind: 1.2 bar
- mass flow rate: 161 g/s

Thus, HFE 7100 parameters enable regular work of the cogenerative micro power plant.

The thermal efficiency of a Carnot cycle: η_{Car} = 32 %

The thermal efficiency of the ORC: η_{ORC} = 10 %

Electrical efficiency of the CHP system: $\eta_{ele,CHP}$ = 4.5 %

Isentropic efficiency (radial microturbine): 70 %

Electrical output: 1.5 kW (rotor speed - 18 000 rpm)

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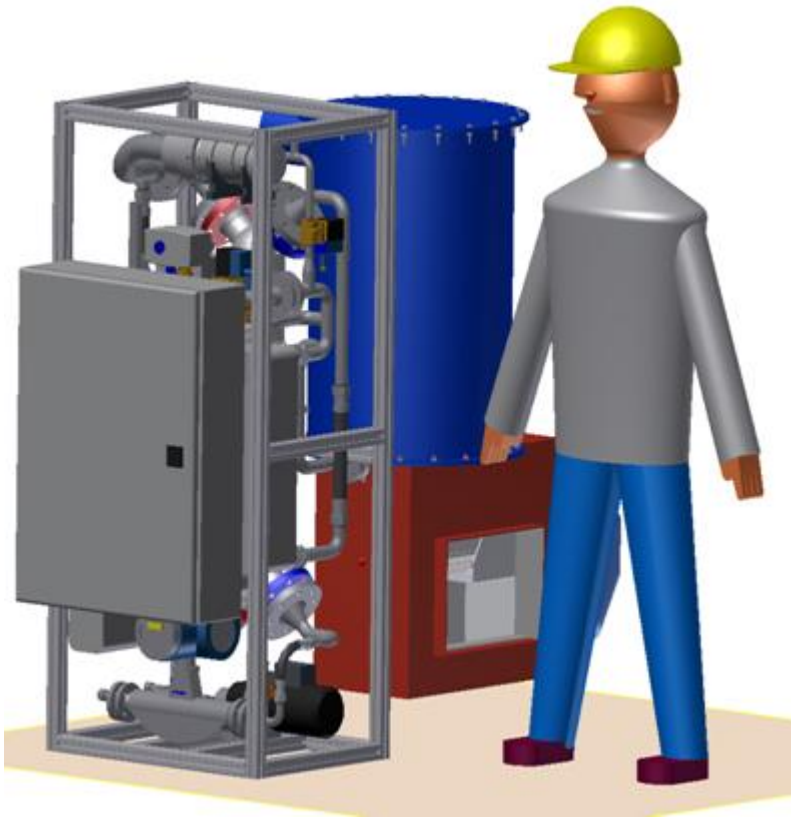

Construction design of a micro power plant – view from the cogeneration module – comparision with a human.

Thank you for your attention

Acknowledgments:

National Project POIG.01.01.02-00-016/08 *Model agroenergy complexes as an example of distributed cogeneration based on a local renewable energy sources.*