

# Cooperation of the Organic Rankine system with a cogeneration steam power plant – case study

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**Abstract.** The cooperation of the ORC system with a cogeneration steam power plant has been considered. A district heating network is supplied from a bleeder turbine. An ORC system can utilize redundant heat, especially during the summer season, when only domestic hot water needs are served. The aim of the study was a selection of an extraction steam flow to produce the maximum electric power in an ORC system and also to cover the changing heating demand in the district heating network under consideration. Various values of extraction steam flows obtained from the bleeder turbine were considered. For a given extraction steam flow, the optimum ORC size has been adjusted. The average annual efficiency of the ORC was estimated at 0,12 (for the cyclic temperatures 120/35°C). The shortest simple payback time has been estimated at 4 years, assuming that heat from the bleeder turbine meets the heating demand throughout the year and thus the ORC system also operates throughout the year.

## 1 Introduction

Organic Rankine Cycle (ORC) technology is a reliable method to convert low grade heat into electricity. ORC systems are used in many renewable energy applications (geothermal, biomass, solar thermal) [1, 2]. ORC units range from micro-scale (a few kWe) for domestic cogeneration to large multi-megawatt geothermal power plants. Waste heat recovery is an emerging field for ORC technology. Medium and large size plants recover heat from gas turbines, internal combustion engines or industrial processes [3].

The combined cycle power plant (CCPP) could be more efficient than the single cycle, because of its use of low grade waste heat. A lot of studies have been conducted on the utilization of the exhaust gas heat from thermal power plants to power organic Rankine cycle plants for further power generation. Tri-generation systems such as combined gas- and steam-turbine cycle power plant (CCPP) integrated with organic Rankine cycle (ORC) and absorption refrigeration cycle (ARC) [4] have also been developed.

The cogeneration steam power plant under consideration supplies heat to the district heating system. During the summer season excess heat appears due to a lack of central heating demand.

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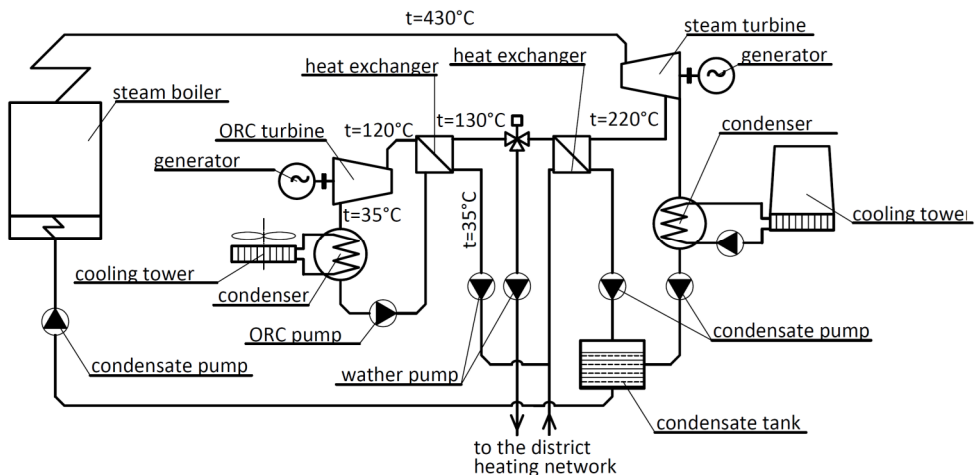
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The aim of this analysis is to adjust the nominal power of the ORC system to variable excess heat available in the considered cogeneration steam power plant. The payback period was used as a basic optimization criterion.

## 2 ORC cooperating with cogeneration steam plant

A schematic diagram of the analysed ORC system was presented in Fig. 1. The ORC system is a part of steam cogeneration power plant. This coal-fired heating plant supplies heat to the district heating network of a small town. The bleeder turbine provides the steam with a temperature of 220°C. This steam transfers heat to the steam-water heat exchanger. Hot water with a temperature of 130°C supplies the district heating network and could also be used as a heat source for ORC system.

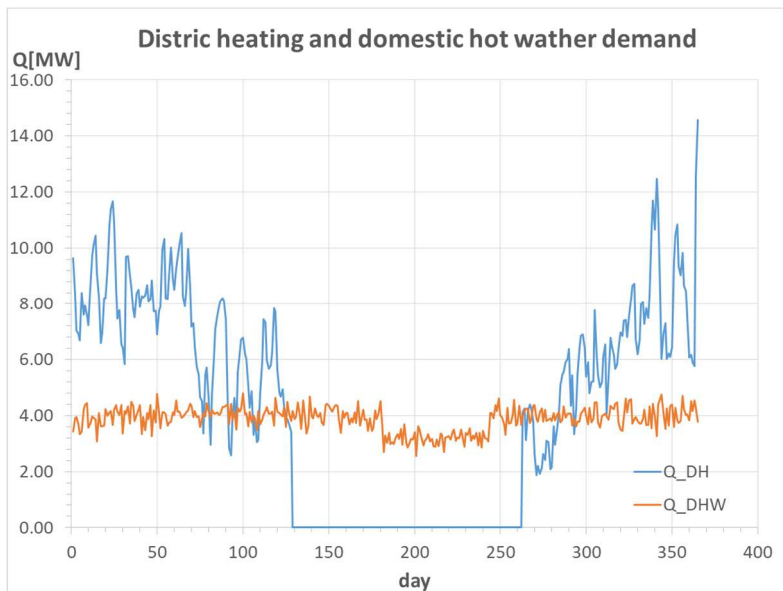
The considered ORC system works with organic fluid (refrigerator) in a range of temperatures between 135°C and 20°C. The thermal efficiency of the ORC cycle was estimated at 0,12 (when the Carnot efficiency for considered temperatures is about 0,21). The ORC system consists of an ORC turbine with an electric generator, a working fluid evaporator (water-refrigerator heat exchanger), a working fluid condenser (cooled by water circulating in a loop with cooling tower) and a liquid pump.



**Fig. 1.** Schematic diagram of the ORC cycle cooperating with cogeneration steam power plant.

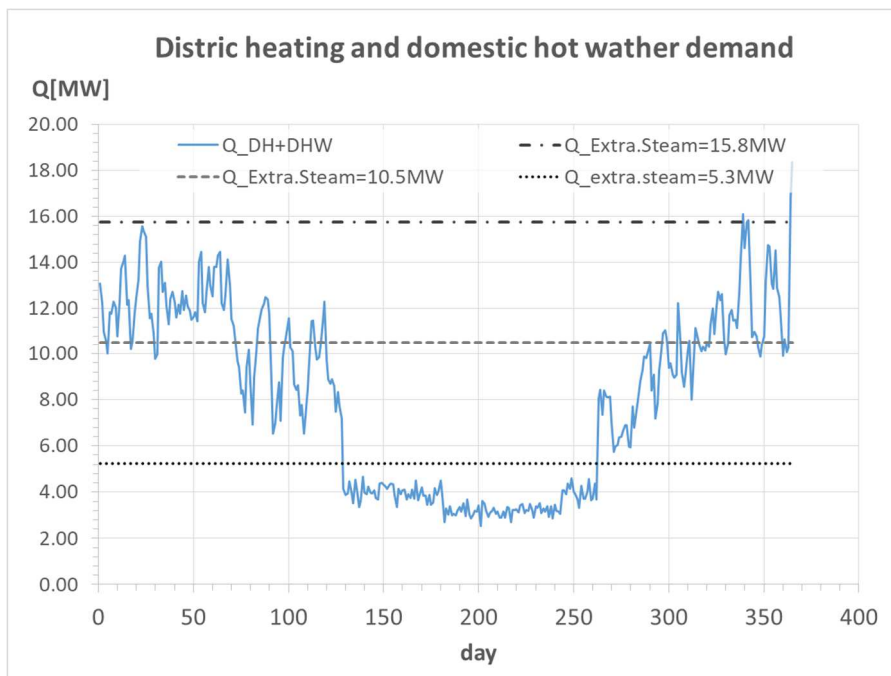
The calculation parameters of the considered district heating network are 16,5 MW for district heating demand and 4 MW for domestic hot water demand (daily average demand for about 16500 residents). The distribution of the district heating demand and domestic hot water demand is shown in Fig. 2. The district heating network only supplies heat for domestic hot water recipients for about 150 days in the year. Both curves presented in Fig.2 was obtained on the basis of measurement data made available by the manager of the analyzed district heating network.

The operation time of an ORC system depends on the amount of bleed steam. When the extraction steam flow increases, the thermal power transferred to the district heating network also increases. Then the ORC system can utilize the unused heat in the district heating network. For larger extraction steam flows, a longer operation time of the ORC system is expected. For low values of extraction steam flows, more energy is consumed by the domestic hot water demand.



**Fig. 2.** The distribution of district heating (DH) and domestic hot water demand (DHW) in a year.

Three variants of extraction steam power output values were alternatively considered: 5,3 MW (respectively 134 days of ORC operation in a year), 10,5 MW (respectively 239 days of ORC operation in a year) and 15,8 MW (respectively 360 days of ORC operation in a year). The extraction steam power output values and the total district heating network demand were compared in Fig. 3.



**Fig. 3.** The heating demand and extraction steam power output (three variants).

### 3 Results of analysis

For each value of the extraction steam power output, an analysis of the optimum size of ORC system was conducted. The basic parameter characterizing the ORC unit is its electric power output. On the one hand, this power output is crucial for profits from energy sales, and on the other hand it is connected with the price of an ORC unit. The simple payback time (SPBT) was used to evaluate the best solution. Choosing the best value of extraction steam power output turned out to be useful, but it was not sufficient enough to indicate the optimal size of an ORC unit.

Twenty different ORC units (with different electric power outputs) were analysed for each value of extraction steam power. For each case the following parameters were calculated:

- maximum and average (annually) electric power output,
- incidence of maximum power output (days per year),
- incidence of average power output (days per year),
- relative operation time with maximum power output (regarding the possible operating days per year),
- relative operation time with average power output (regarding the possible operating days per year),
- profits from electricity sales,
- SPBT (complying investment costs of ORC unit, increasing with electric power output).

The investment costs of the ORC unit was estimated in a range of 1600-2000 €/kWe [5]. The selected calculation values of the considered ORC units for the extraction steam power 15,8 MW are presented in Table 1. The optimal parameters of the ORC unit are shaded in one column of this table.

For the set value of the extraction steam power output, the key factor is matching the ORC power to the available heat. It is good when the device operates the comparable number of days with a maximum and average power output. In increasing the ORC power output, the operating time decreases. At the same time the difference between the operating time with a maximum and the average power output increases.

**Table 1.** Comparison of ORCs power output for extraction steam power 15,8 MW (operation time for ORC is 360 days per year).

<b>max</b> ORC power output	kWe	1640	1330	880	520	340	140
<b>average</b> ORC power output	kWe	950	890	700	480	330	130
Incidence of <b>max</b> ORC power output	day	1	134	184	278	333	355
Incidence of <b>average</b> ORC power output	day	167	181	226	293	337	355
Relative operating time with <b>max</b> power	%	0,3	37,2	51,1	77,2	92,5	98,6
Relative operating time with <b>average</b> power	%	46,4	50,3	62,8	81,4	93,6	98,6

Dependency between simple payback time (SPBT) and ORC power output for a set value of the extraction steam power is presented respectively in Fig. 4, Fig. 5 and Fig. 6. Each figure also shows the profits from electric energy sales for the considered ORC units.

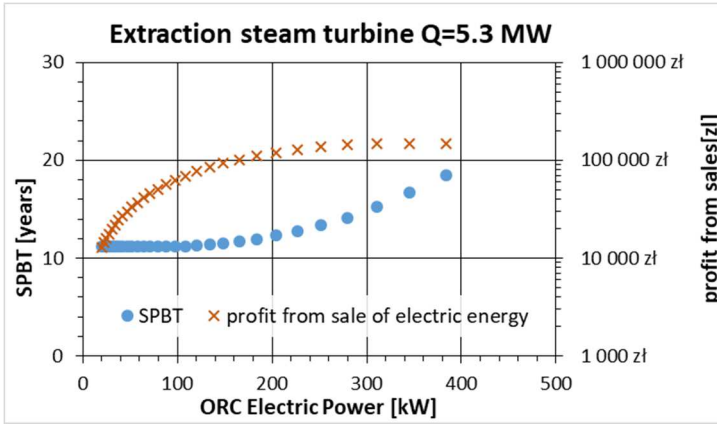


Fig. 4. SPBT versus ORC electric power output for the extraction steam 5,3 MW.

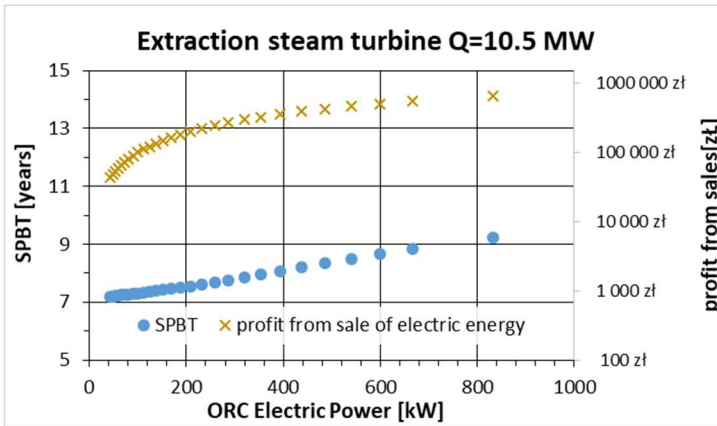


Fig. 5. SPBT versus ORC electric power output for the extraction steam 10,5 MW.

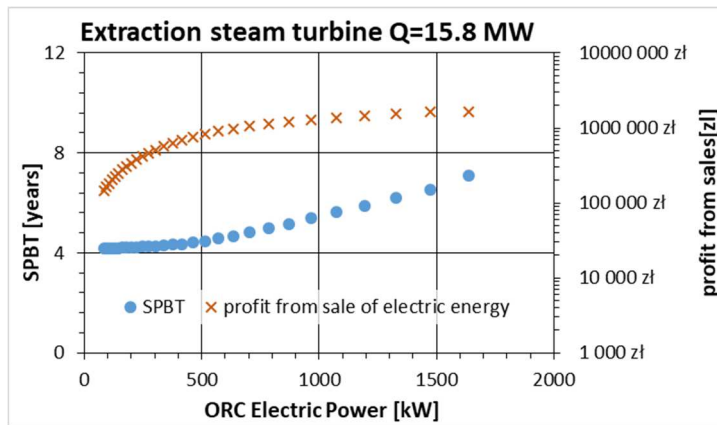


Fig. 6. SPBT versus ORC electric power output for the extraction steam 15,8 MW.

In comparing SPBTs, the optimum extraction steam power could be indicated as a value of 15,8 MW. The shortest SPBT was about 4 years and it was obtained when the entire heating demand was covered by extraction steam. For lower extraction steam power values an ORC system operates distinctly shorter and the best SPBTs were respectively about 7 years for extraction steam power 10,5 MW and more than 10 years for extraction steam power 5,3 MW.

Taking into account the operation time with the maximum and average power output, the maximum ORC power was sought (corresponding to the maximum electricity production) when the ORC unit can operate efficiently as long as possible during the year. Considering the data in Fig.6, it can be stated that for some ORC power output, profits from sold energy cease to increase quickly and SPBT begins to increase significantly. After these analysis, the variant of electricity production at the level of 520 kWe was adopted as most favorable for extraction steam power 15,8 MW.

For the 5,3MW extraction steam power, the optimal ORC power output was about 165 kWe. For the 10,5MW extraction steam power, the optimal ORC power output was about 260 kWe.

## 4 Conclusions

The cooperation of the ORC system with a cogeneration steam power plant has been considered. The bleeder turbine provides heat for a district heating network. Hot water (130°C ) supplying the district heating network was also used as a heat source for the ORC system.

The simple payback time (SPBT) has been used to choose the best value of the extraction steam power output. The shortest SPBT was about 4 years and it was obtained when the entire heating demand was covered by extraction steam (for extraction steam power output 15,8 MW) and the ORC system operated almost throughout the year.

For each value of the extraction steam power, the optimal ORC power output could be indicated taking into account the time of its operation with a maximum and average power output, the amount of electricity produced and the investment costs (dependent on power output). For the selected extraction steam power output (15,8 MW), the optimal ORC power output was about 520 kWe.

## References

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