University of Belgrade
Faculty of Mechanical Engineering

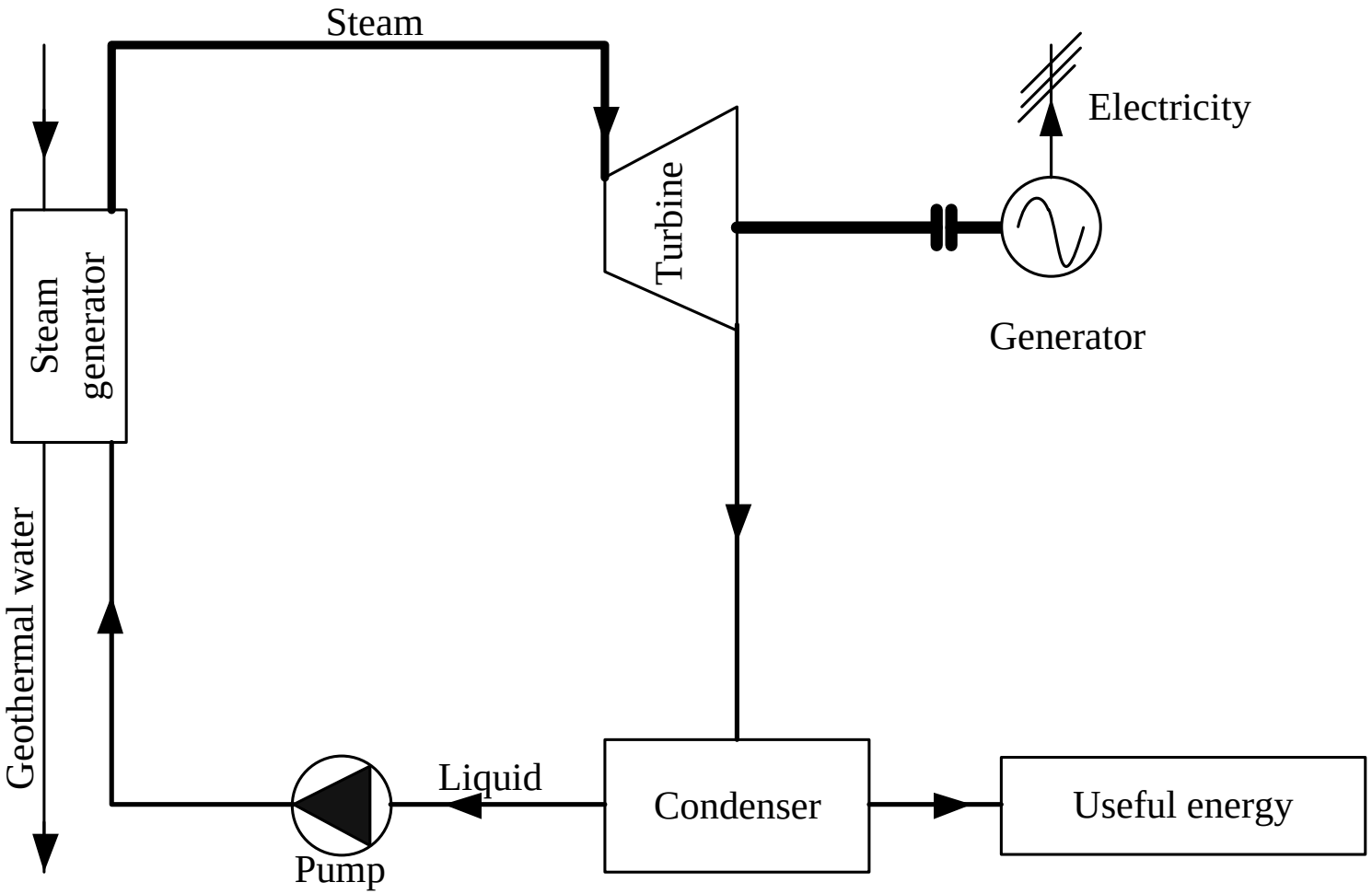
THE USE OF GEOTHERMAL ENERGY IN ORGANIC RANKINE CYCLE (ORC)

Authors: Milena Otović, Mirko Komatina, Nedžad Rudonja, Uroš Milovančević, Srđan Otović, Snežana Stevanović

DESCRIPTION OF THE SYSTEM

- ORC is similar to the cycle of conventional plant with steam turbine and coil-fired boiler.
- Organic fluid – boiling point lower than water.
- The lower temperature heat sources for electricity production – biomass, industrial waste heat, geothermal water, solar energy…
- A typical range of temperatures for systems using ORC is 80 – 140°C (60 – 350°C).

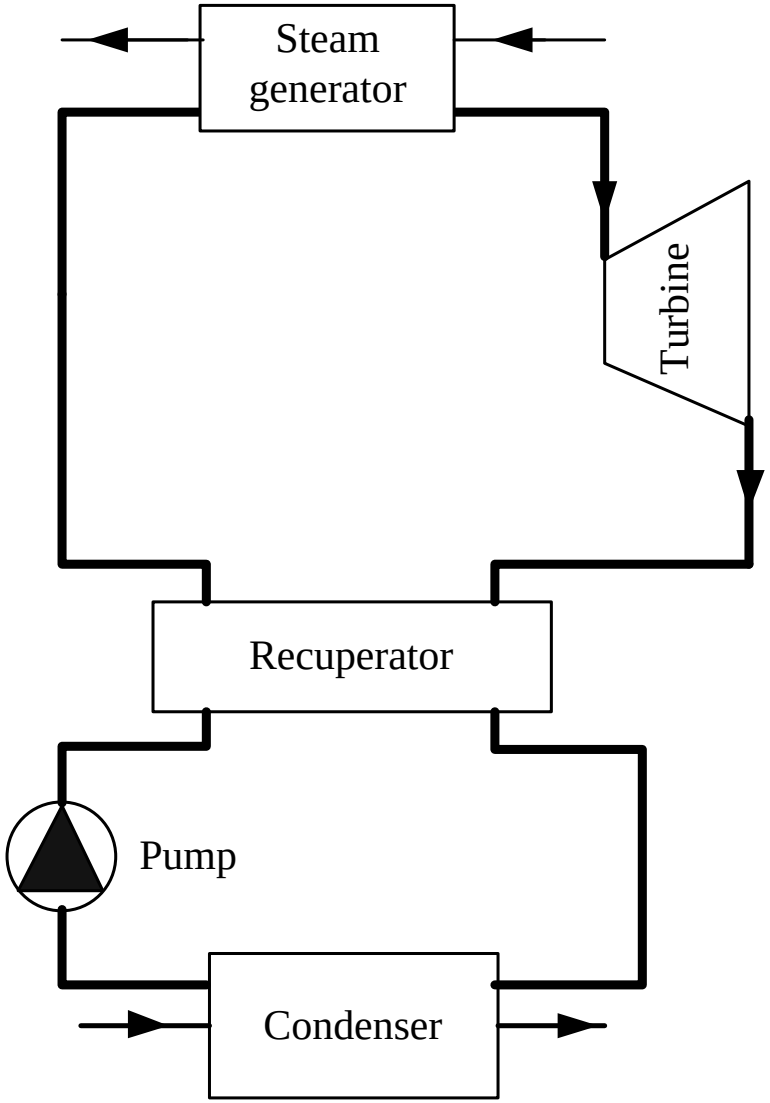
DESCRIPTION OF THE SYSTEM



SELECTION OF THE WORKING FLUID

- Crucial in ORC systems with low temperature heat sources.
- The heat exchange can be very inefficient (thermal and physical characteristics of the fluid and working conditions).
- The end of the expansion process – superheated vapor (temperature higher than the condensation temperature) – heating of the liquid fluid before entering the evaporator, placing the heat exchanger.

SELECTION OF THE WORKING FLUID



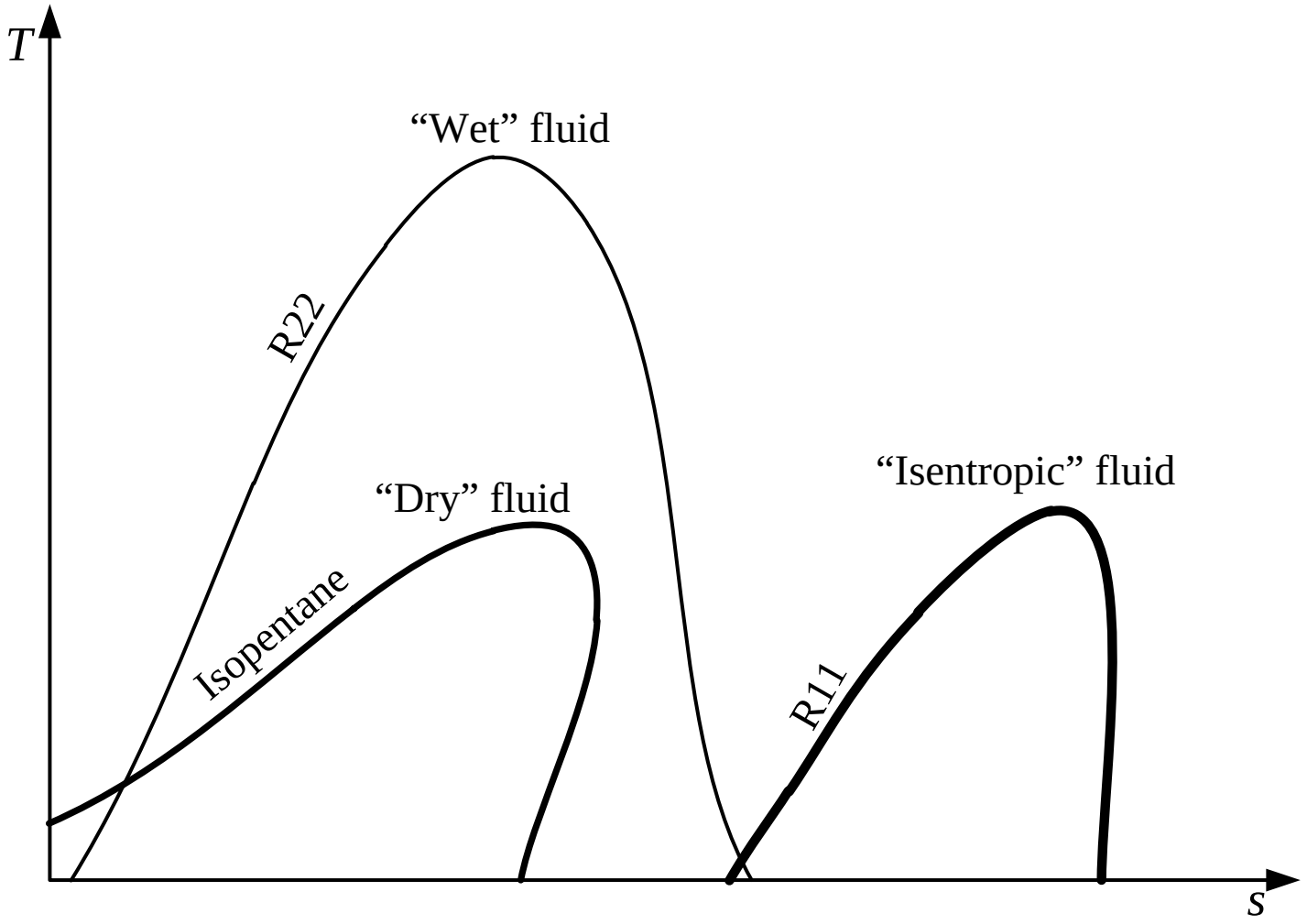
SELECTION OF THE WORKING FLUID

- Fluid with a large latent heat and density – required fluid flow, the size of plants and pump power.
- The maximum temperature of the used heat source – chemical stability of fluid.
- The freezing temperature – lower than the lowest operating temperature of the cycle.
- Fluid – environmentally friendly, readily available, inexpensive, with acceptable working pressures, not corrosive, flammable and toxic
- The most commonly used: R134a, R245fa, isobutane, pentane, propane, fluorocarbons.

SELECTION OF THE WORKING FLUID

- The slope of saturated vapor curve of the working fluid in the $T - s$ diagram:
  - positive (isopentane) – "dry" fluids,
  - negative (R22, water) – "wet" fluids,
  - vertical (R11) – "isentropic" fluids.
- "Wet" fluids have to be overheated, while many organic fluids, which may be a "dry" or "isentropic", it is not necessary to overheat.

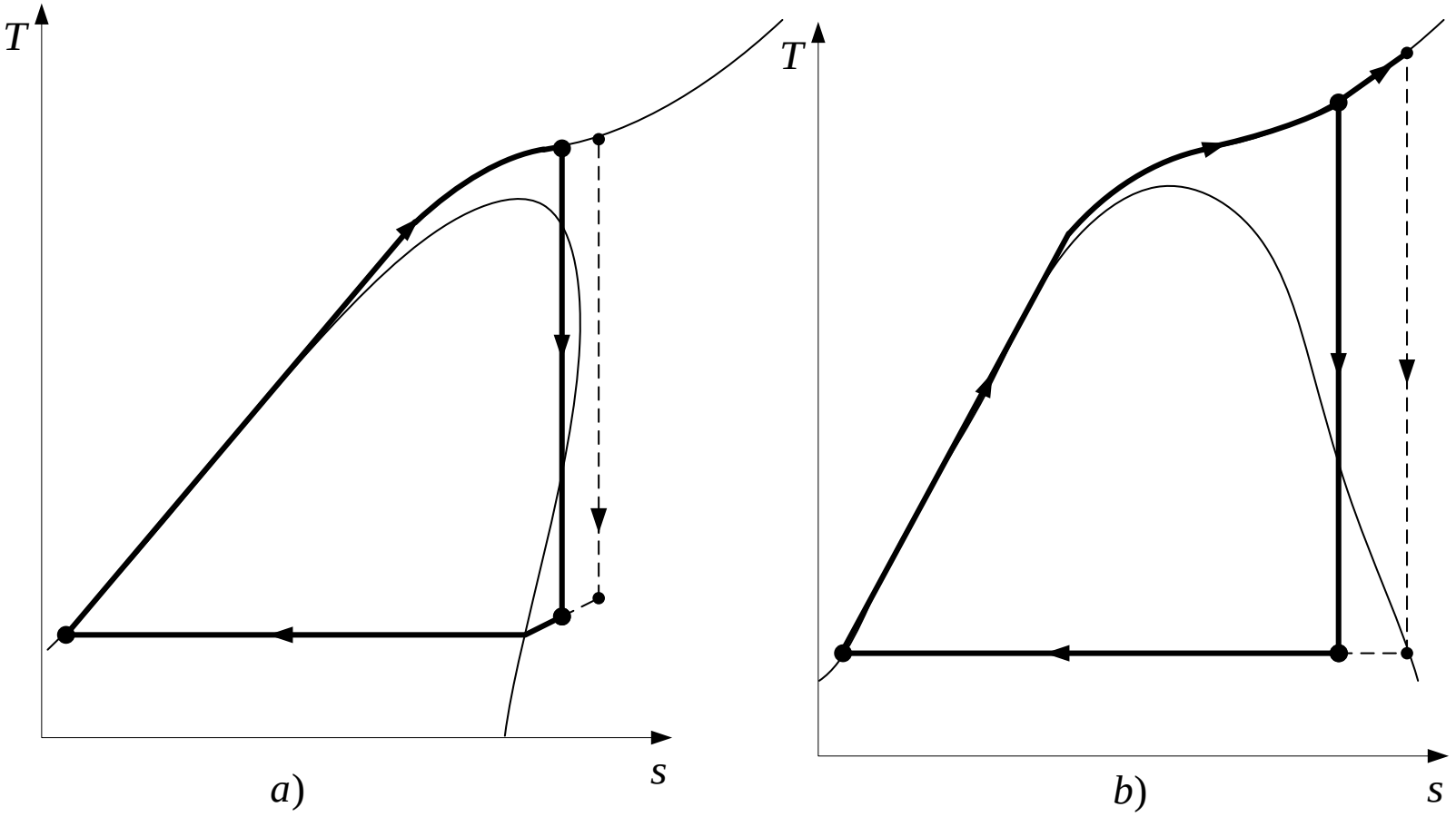
SELECTION OF THE WORKING FLUID



SELECTION OF THE WORKING FLUID

- Supercritical cycle:
  - fluid is "too dry" – vapor at the end of the expansion process would be superheated – additional cooling load in the condenser,
  - vapor temperature must be high enough so the expansion in the turbine do not enter two-phase region,
  - fluids with a negative slope of saturated vapor curve – superheating necessary to avoid two-phase region at the end of the expansion.

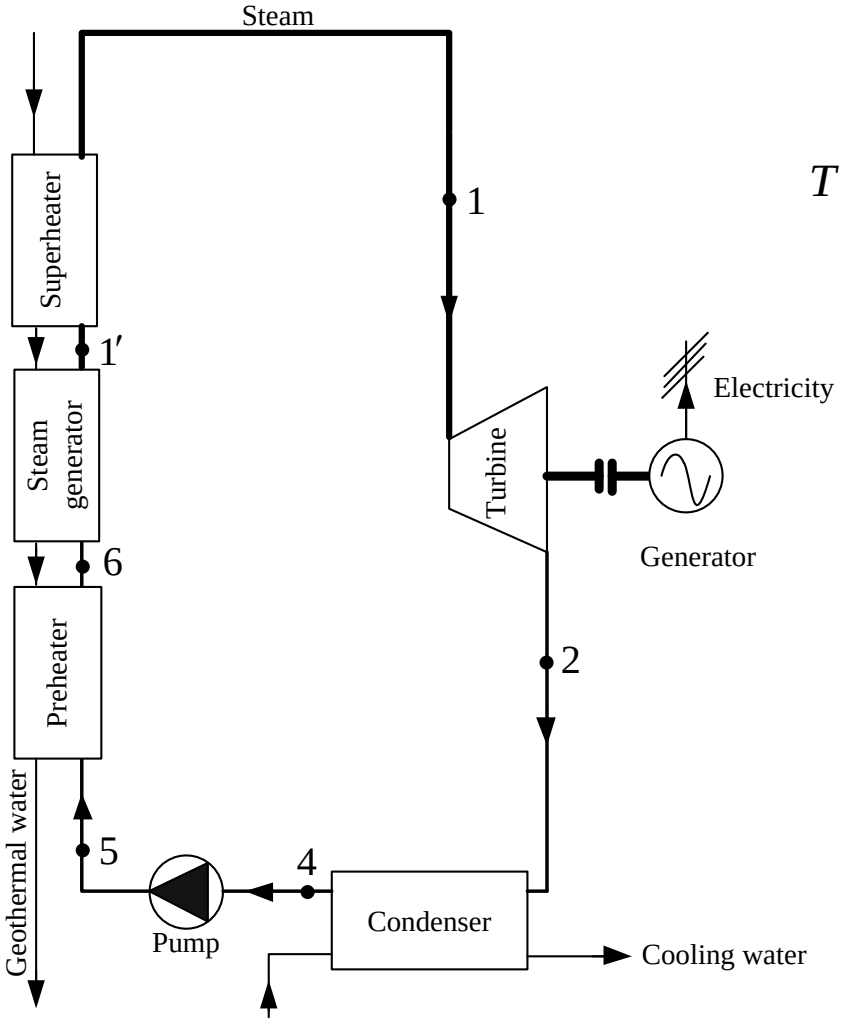
SELECTION OF THE WORKING FLUID



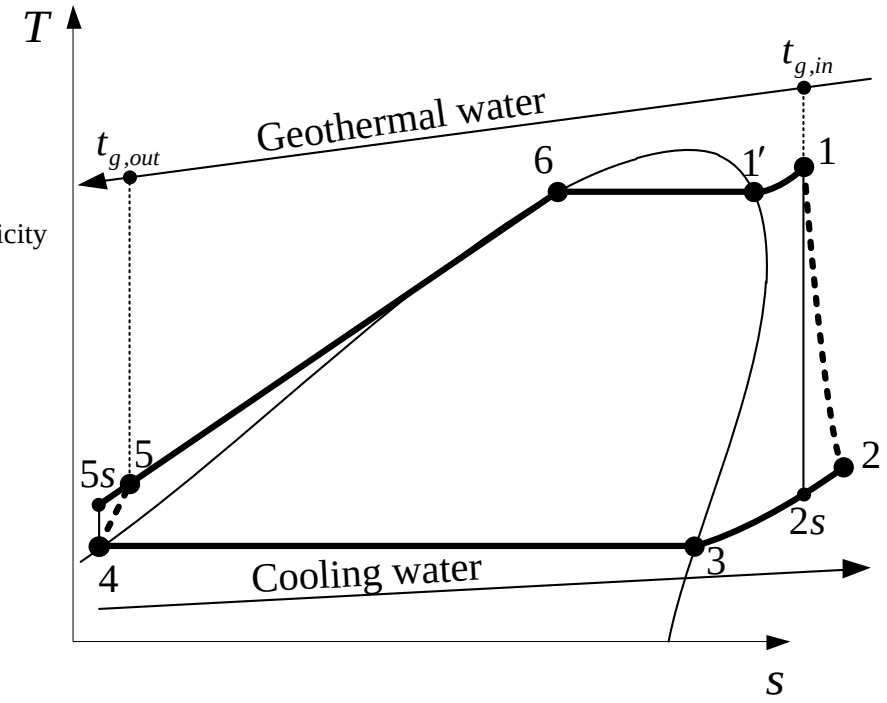
MATHEMATICAL MODEL OF THE SYSTEM

- Geothermal water from the locality Vranjska Banja with a highest temperature of 96°C as heat source for driving ORC system.
- The mass flow of geothermal water is 77 kg/s, and it is considered a mass flow of 20 kg/s for this system.

MATHEMATICAL MODEL OF THE SYSTEM



a)



b)

MATHEMATICAL MODEL OF THE SYSTEM

- Heat submitted by the geothermal source in the ORC to working fluid is equal to

$$Q = m \cdot (h_1 - h_5)$$

- Power obtained from the turbine is

$$P_{tur} = m \cdot (h_1 - h_2) = m \cdot \eta_{tur} \cdot (h_1 - h_{2s})$$

- The power for the pump:

$$P_{pum} = m \cdot (h_5 - h_4) = \frac{m \cdot (h_{5s} - h_4)}{\eta_{pum}}$$

- The mass flow of the working fluid is

$$m = \frac{m_g \cdot c_p \cdot (t_{g,in} - t_{g,out})}{h_1 - h_6}$$

MATHEMATICAL MODEL OF THE SYSTEM

- Isentropic efficiency of turbine and pump:

  $\eta_{tur} = 0{,}85$ and $\eta_{pum} = 0{,}75.$

- Based on those values it can be found enthalpy of the state point 2 and 5:

  $$h_2 = h_1 + \eta_{tur} \cdot (h_1 - h_{2s})$$

  $$h_5 = h_4 + \frac{(h_{5s} - h_4)}{\eta_{pum}}$$

- The thermodynamic efficiency of ORC system:

  $$\eta_{td} = \frac{P_{tur} - P_{pum}}{Q}$$

THE CALCULATION RESULTS

- Geothermal water is cooled to a temperature of 80°C at the exit of the evaporator, and used to preheat the fluid.
- The temperature of the cooling water is 20°C.
- The temperature differences are:

  $\Delta t_{isp} = 6°C$ and $\Delta t_{kd} = 8°C$.
- The evaporation and condensing temperatures:

  $t_{isp} = 74°C$ and $t_{kd} = 28°C$.
- The temperature of the working fluid at the exit of the superheater is $t_{pr} = 84°C$.
- Working fluid – R245fa.

THE CALCULATION RESULTS

- mass flow of the working fluid R245fa: 7,9 kg/s,
- heat delivered to the working fluid (evaporation and superheating): 2016,6 kW,
- turbine power: 258,8 kW,
- pump power: 4,5 kW,
- thermodynamic efficiency: 0,126.

Comparison ORC to conventional system for el. energy production

- TEKO B Drmno (Kostolac) – projected power of 340 MW in lignite consumption of 106,5 kg/s (8373,6 kJ/kg), with a carbon content in fuel C = 25,38%. It is considered that the loss in the boiler is 2,8% - burn out 103,5 kg/s.

lignite consumption for 258,8 kW	0,081 kg/s
annually lignite consumption	2556,6 t/year
volume of CO_2	0,037 Nm^3/s
emission of CO_2	0,074 kg/s
emission of CO_2 per kg lignite	0,936 kg CO_2/kg
annually emission of CO_2	1176700 Nm^3/year
annually emission of CO_2	2326,3 t CO_2/year

Conclusion

- In ORC electricity is produced by using decentralized heat sources – an important advantage over conventional systems.
- The waste heat or heat from renewable sources – reduction of CO_2 emission and consumption of fossil fuels for electricity production.
- Production of electrical energy of 260 kW using geothermal sources – approximately 2600 tons of lignite per year (about 2350 tons of CO_2).
- It is preferable that the temperatures of the geothermal heat sources are high as much as possible, and also their flow rate availability (the thermodynamic efficiency of the cycle).

Thank you!