



EFFICIENT LOW TEMPERATURE GEOTHERMAL BINARY POWER

Computer modelling and
optimization of Rankine cycles for
low temperature power generation

Kontoleonos Evgenia



Centre for Renewable Energy Sources

LOW-BIN PROJECT

Low-Bin Final Workshop : Braunau 28 August

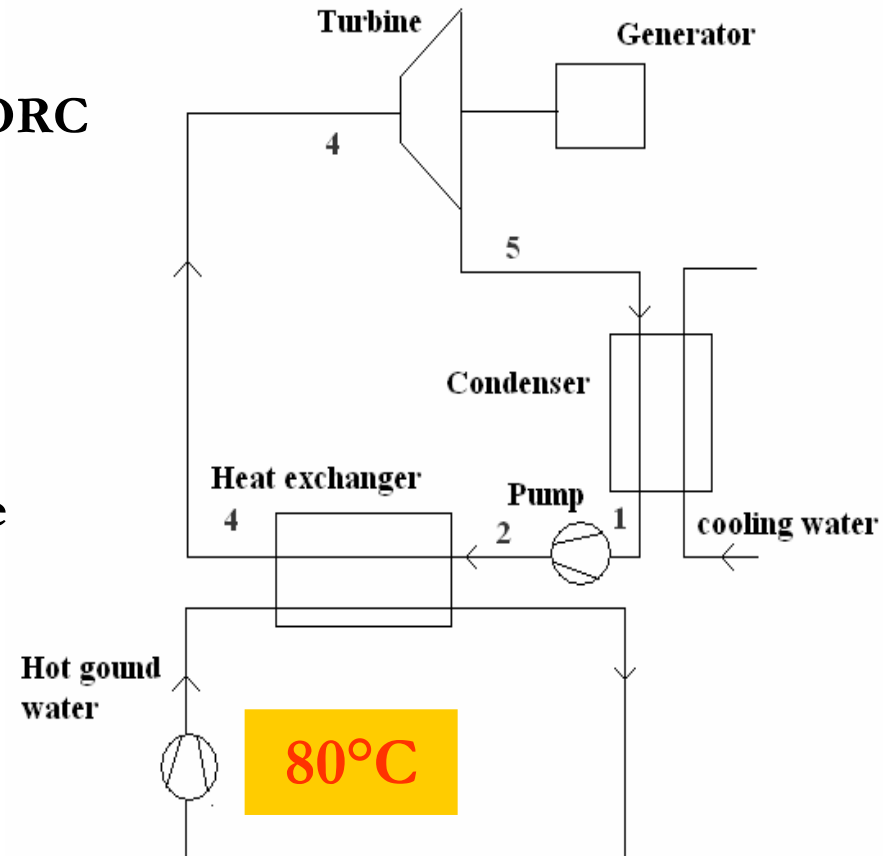
Objective of the projects

- Development and demonstration of the ORC power plant with geothermal water temperature of $65-90^{\circ}\text{C} \rightarrow 80^{\circ}\text{C}$

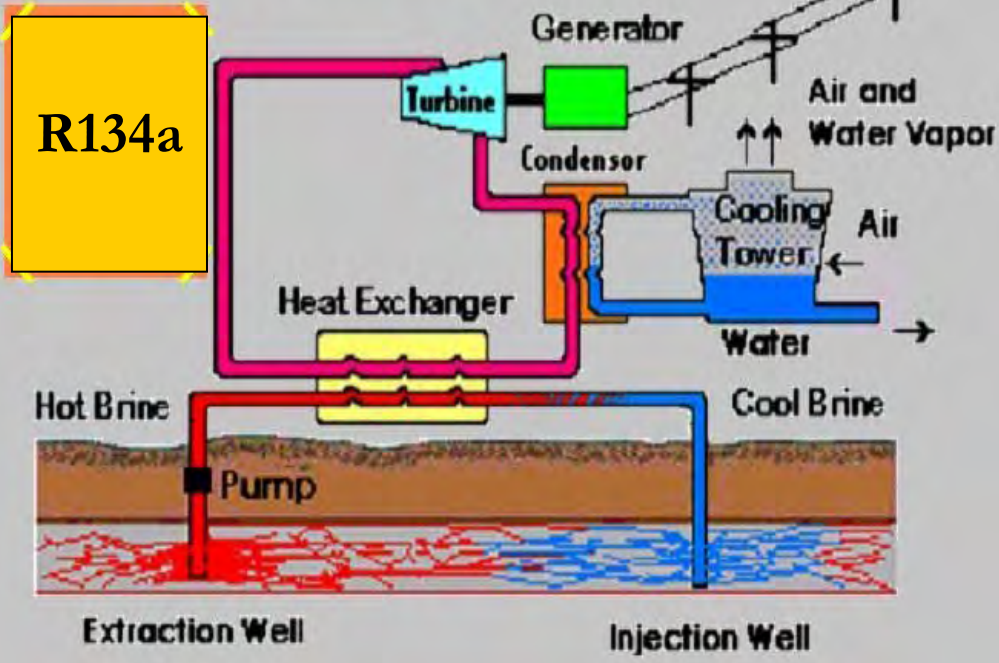
Our Objective

- Computer Modelling of the Rankine Cycle
- Optimization of the Rankine Cycle

↓
Optimal Rankine Cycles



Binary Cycle Power



- ✓ Modelling of the condenser
- ✓ Modelling of the heat exchanger

Cooling Heat Exchanger



shell and tube condenser

Geothermal Heat Exchanger



*plate heat exchanger (PHE)
with corrugated parallel plates*

Development of a software which uses the fluids' properties and provides us with the thermodynamic properties of each point on the Rankine Cycle.



Optimization of the Rankine cycle

Cooling Heat Exchanger

**Overall heat transfer
coefficient :**

$$U_o = \frac{1}{\frac{A_o}{A_i} \frac{1}{h_i} + \frac{A_o \ln(r_o/r_i)}{2\pi kL} + \frac{1}{h_o}}$$

**Laminar condensation
on tubes surface :**

$$h_o = 0.725 \left[\frac{\rho(\rho - \rho_v) g h_{fg} k_f^3}{\mu_f d (T_g - T_w)} \right]^{0.25}$$

**Turbulent flow of the
cooling water inside the
tubes :**

$$h_i = \frac{Nu k}{D}$$

$$Nu = 0.023 Re^{0.8} Pr^{0.4}$$

$$Re = \frac{u \cdot D \cdot \rho}{\mu}$$

Overall heat transfer coefficient for each phase:

Single phase flow

$$Re = \frac{u \cdot L \cdot \rho}{\mu}$$

$$c_f = \frac{0.074}{Re^{0.2}} - \frac{1050}{Re}$$

$$St = \frac{c_f}{2} \cdot \frac{1}{Pr^{\frac{2}{3}}}$$

$$Nu = St \cdot Re \cdot Pr$$

$$h_{sp/l, g/gw} = \frac{Nu \cdot k}{L}$$

$$U_{sp/l} = \frac{1}{\frac{1}{h_{sp/l}} + \frac{\Delta x}{ktit} + \frac{1}{h_{gw}}}, U_{tp} = \frac{1}{\frac{1}{h_{tp}} + \frac{\Delta x}{ktit} + \frac{1}{h_{gw}}}$$

$$U_{sp/g} = \frac{1}{\frac{1}{h_{sp/g}} + \frac{\Delta x}{ktit} + \frac{1}{h_{gw}}}$$

Liquid \Rightarrow Two Phase \Rightarrow Vapor

Evaporation heat transfer –Two phase

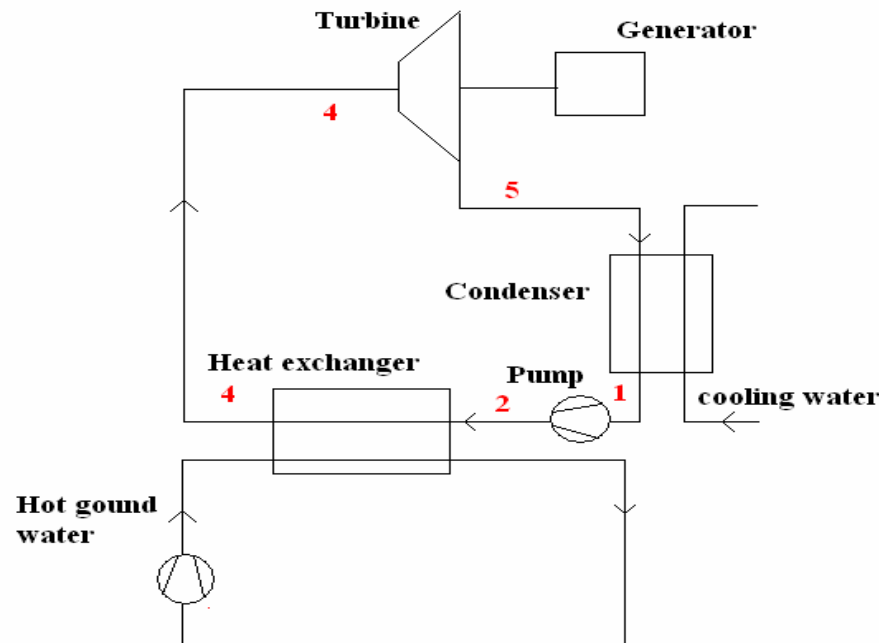


$$h_{wf,tp} = C \left(\frac{k_l}{D_e} \right) \left[\frac{Re_l^2 h_{fg}}{L_p} \right]^{0.4124} \left(\frac{p}{p_{cr}} \right)^{0.12} \left(\frac{65}{\beta} \right)^{0.35}$$

In order to optimize the Rankine cycle of the plant we had to define:

1. The variables of the optimization

- the pressure of the liquid working fluid at the pump outlet, p_2
- the pressure of the liquid working fluid at the pump inlet, p_1
- the mass flow rate of the working fluid in the cycle, \dot{m}_{wf}



2. The objectives of the optimization :

- **Maximize** net overall efficiency of the plant

$$\eta_{cycle} = \frac{N_{elect} - N_{pumps}}{Q_{ground}} = \frac{\eta_{gen} \cdot \eta_{inv} \cdot (h_4 - h_5) \cdot m_{wf} - N_{pumps}}{(h_{gw1} - h_{gw2}) \cdot m_{gw}}$$

- **Minimize** the cost of the plant
└─ Minimize both Exchangers' surface

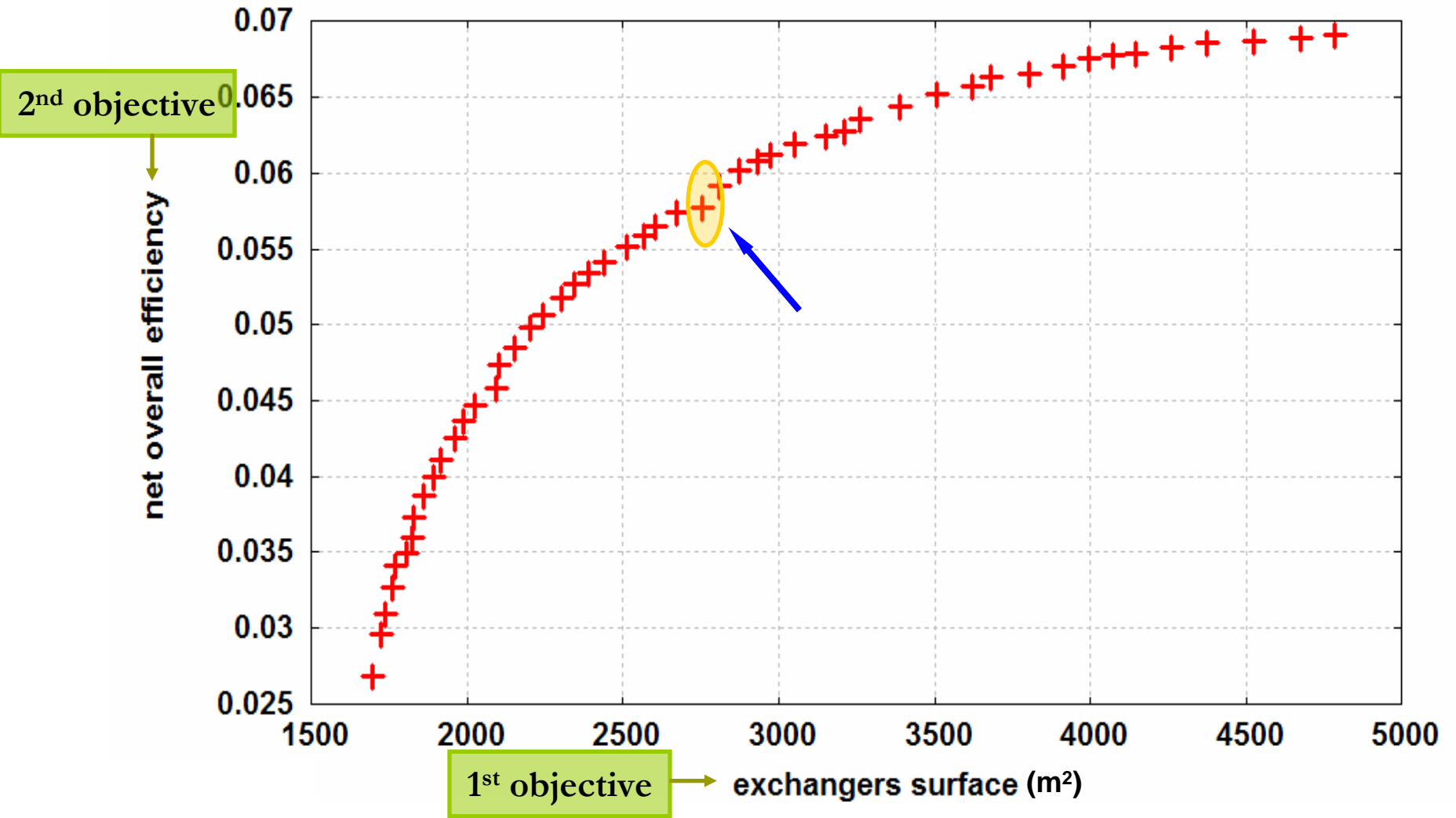
using the **EASY** software code (Evolutionary Algorithm System)
by National Technical University of Athens

<http://velos0.ltt.mech.ntua.gr/EASY>



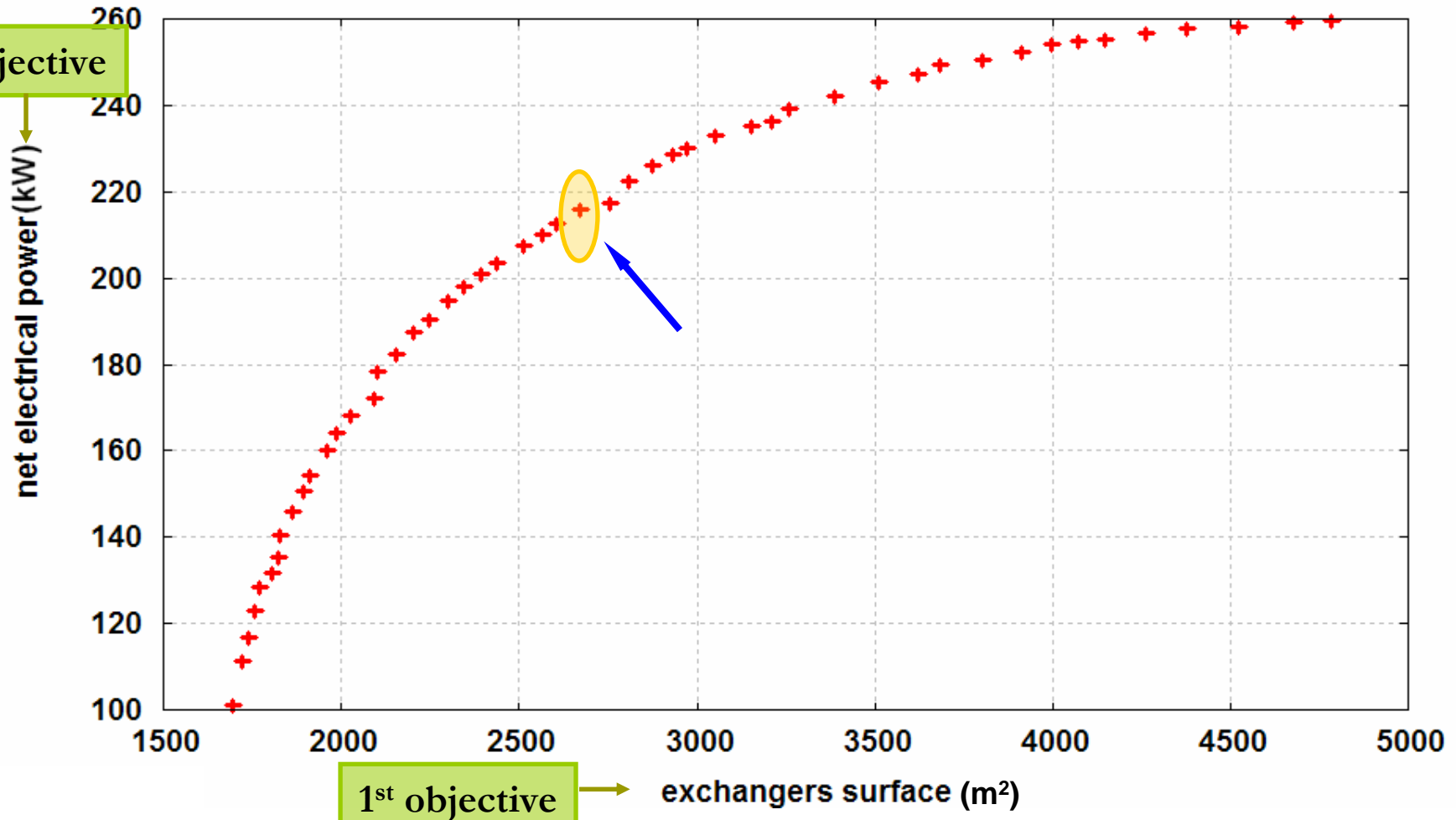
ORC with temperature threshold of 80°C

Optimal solutions



ORC with temperature threshold of 80°C

Optimal solutions

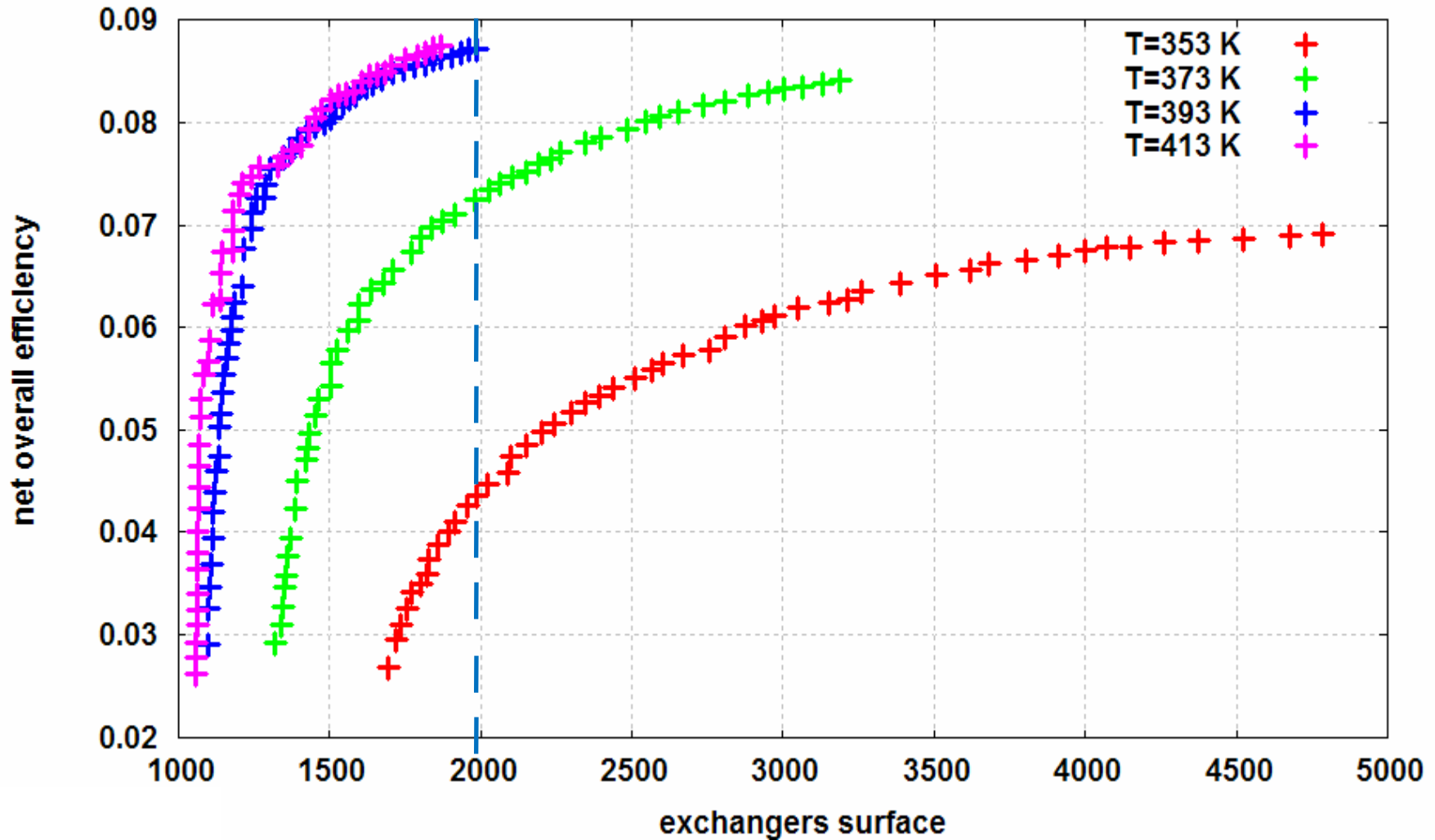


ORC with temperature threshold of 80°C

Parameter	Value
p_2 (kPa)	1876
m_{gr} (kg/sec)	60
m_{R134a} (kg/sec)	18.5
ΔT_H (°C)	15
ΔT_C (°C)	5
R134a pump power (kW)	30
Cooling water flow (kg/sec)	164.5
Surface of the condenser (m ²)	2158
Surface of the heat exchanger (m ²)	597
Total H.E. surface (m ²)	2755
Net conversion efficiency	5.77
Net Electrical Power (kW)	217

P.H.E. - plate heat exchanger		Shell and tube condenser	
Length of the plate (m)	1.43	Diameter of the tube (cm)	1.3
Width of the plate (m)	0.8	Number of tubes	29
Number of plates	520	Length of the condenser (m)	5.5
Total length of the exchanger (m)	1.6		

Temperature threshold at 80, 100, 120, 140 °C



Comparison between different temperature thresholds

Variable	T = 80°C	T = 100°C	T = 120°C	T = 140°C
P ₂ (bar)	16.24	26.51	29.98	29.98
m _{geothermal} (kg/sec)	60	60	60	60
m _{R134a} (kg/sec)	18.5	17.5	16	16
R134a pump power (kW)	22	47	53	53
cooling water flow (kg/sec)	167	161	159	161
Condenser surface (m ²)	1647	1629	1831	1785
Surface of the PHE (m ²)	445	397	154	83
Total H.E. surface (m ²)	2092	2026	1986	1867
Net conversion efficiency	4.6	7.3	8.7	8.8
Net electrical Power (kW)	172	277	332	336



EFFICIENT LOW TEMPERATURE GEOTHERMAL BINARY POWER

Computer modelling and
optimization of Rankine cycles for
low temperature power generation

Kontoleonos Evgenia



Centre for Renewable Energy Sources

LOW-BIN PROJECT

Low-Bin Final Workshop : Braunau 28 August