EFFICIENT LOW TEMPERATURE GEOTHERMAL BINARY POWER

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

Kontoleontos Evgenia

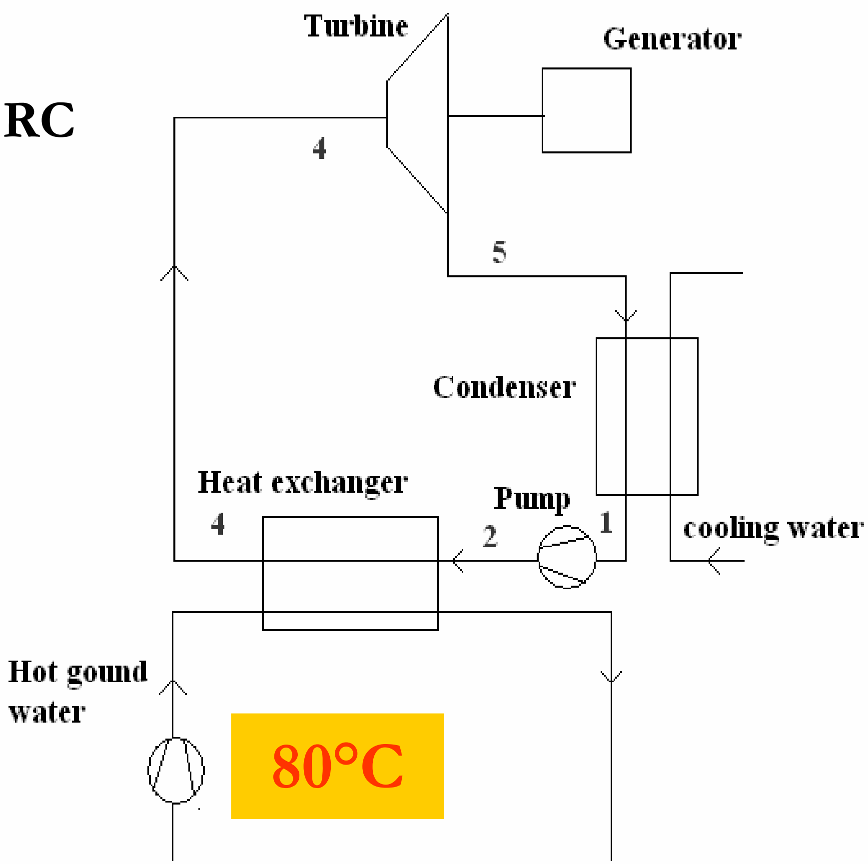
LOW-BIN PROJECT

Centre for Renewable Energy Sources

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°C ⟶ 80°C



Our Objective

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

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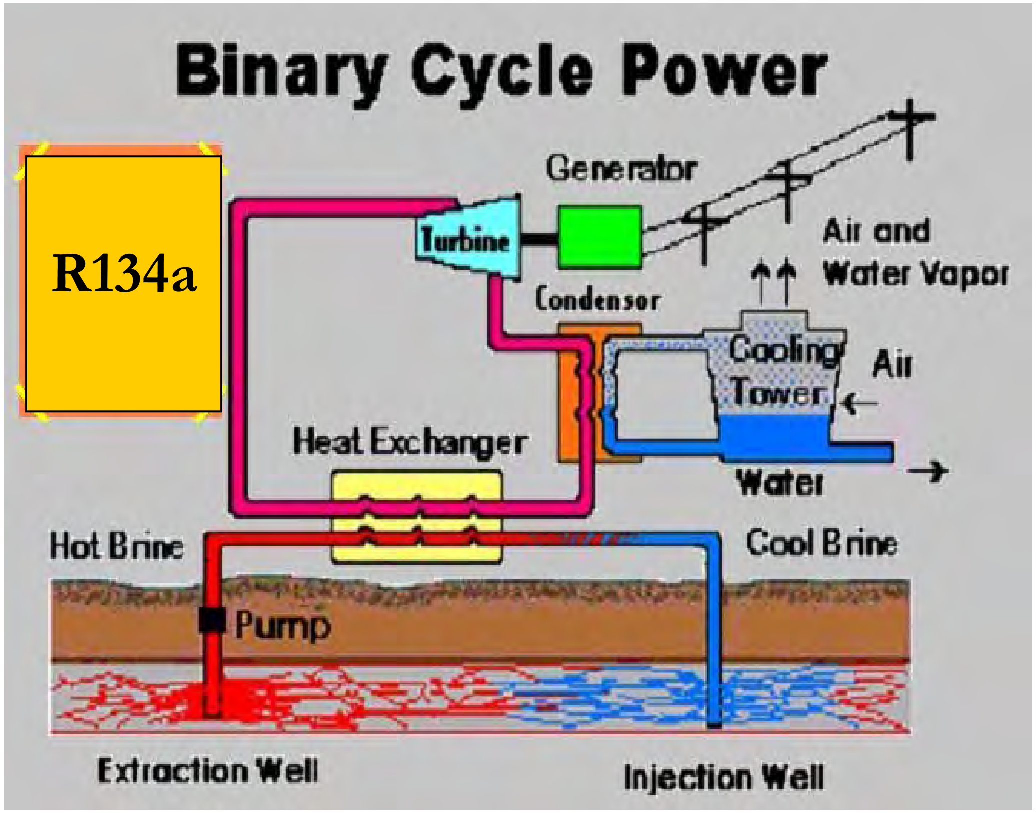
Optimal Rankine Cycles

Modelling Rankine Cycle's Components



- ✓ 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 :

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

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 :

$$h_i = \frac{Nuk}{D}$$

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

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

Geothermal Heat Exchanger

Overall heat transfer coefficient for each phase:

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

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

Single phase flow

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

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

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

$$Nu = St \cdot \mathrm{Re} \cdot \mathrm{Pr}$$

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

Liquid ⇒ Two Phase ⇒ Vapor

Evaporation heat transfer –Two phase

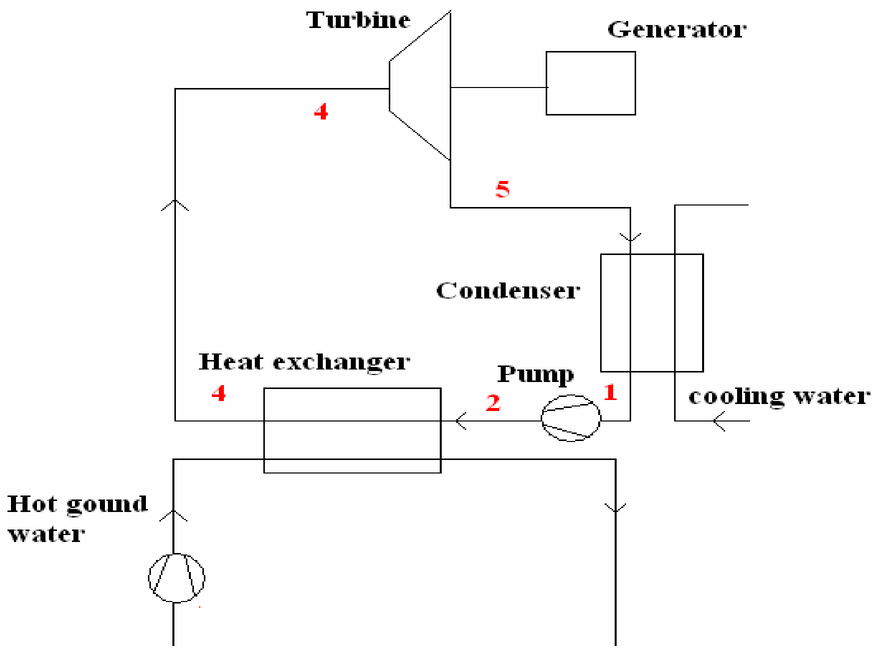
↓

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

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, $\dot{m}_{wf}$



Rankine cycle optimization

2. The objectives of the optimization :

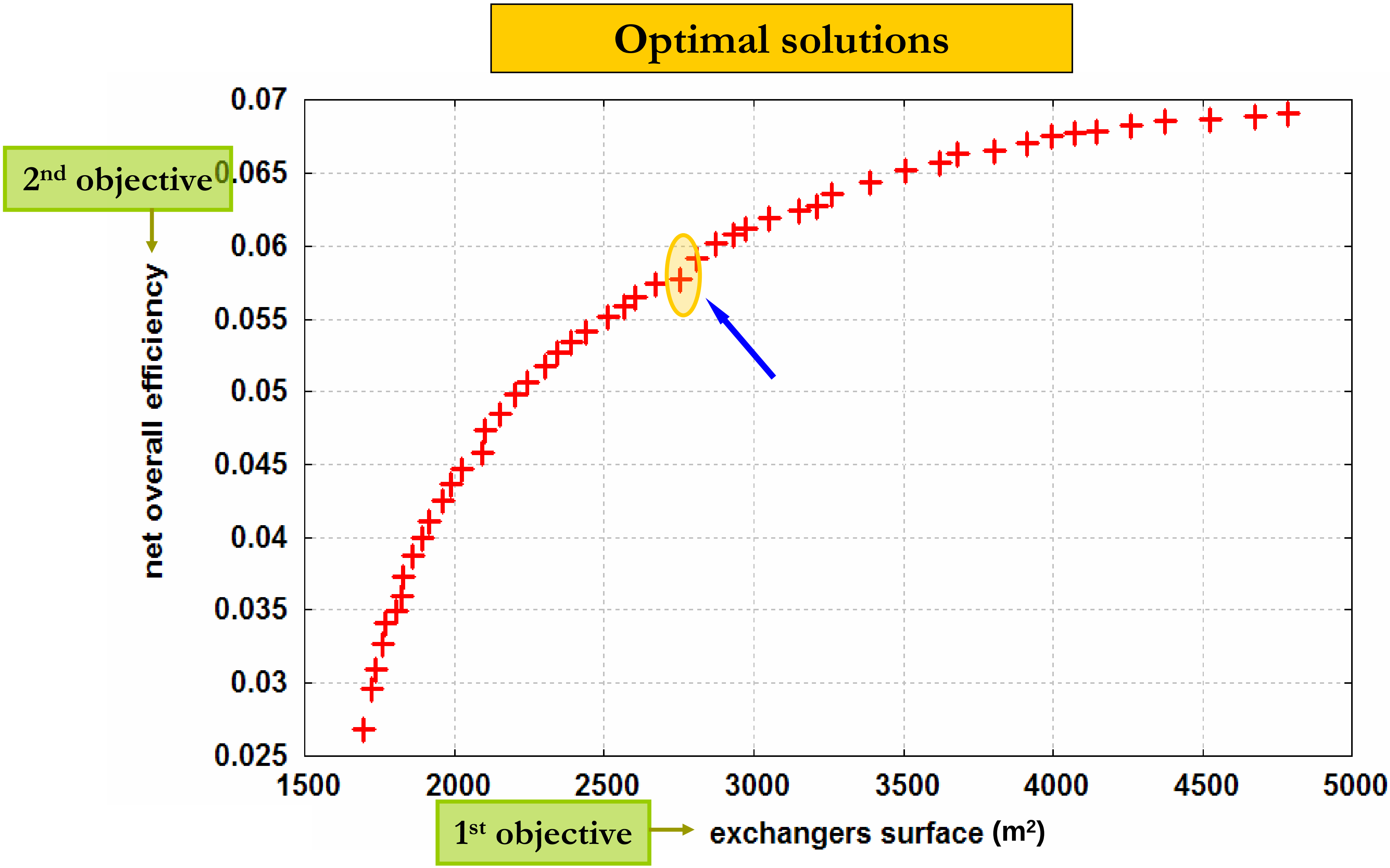
- **Maximize** net overall efficiency of the plant

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

- **Minimize** the cost of the plant → Minimize both Exchangers' surface

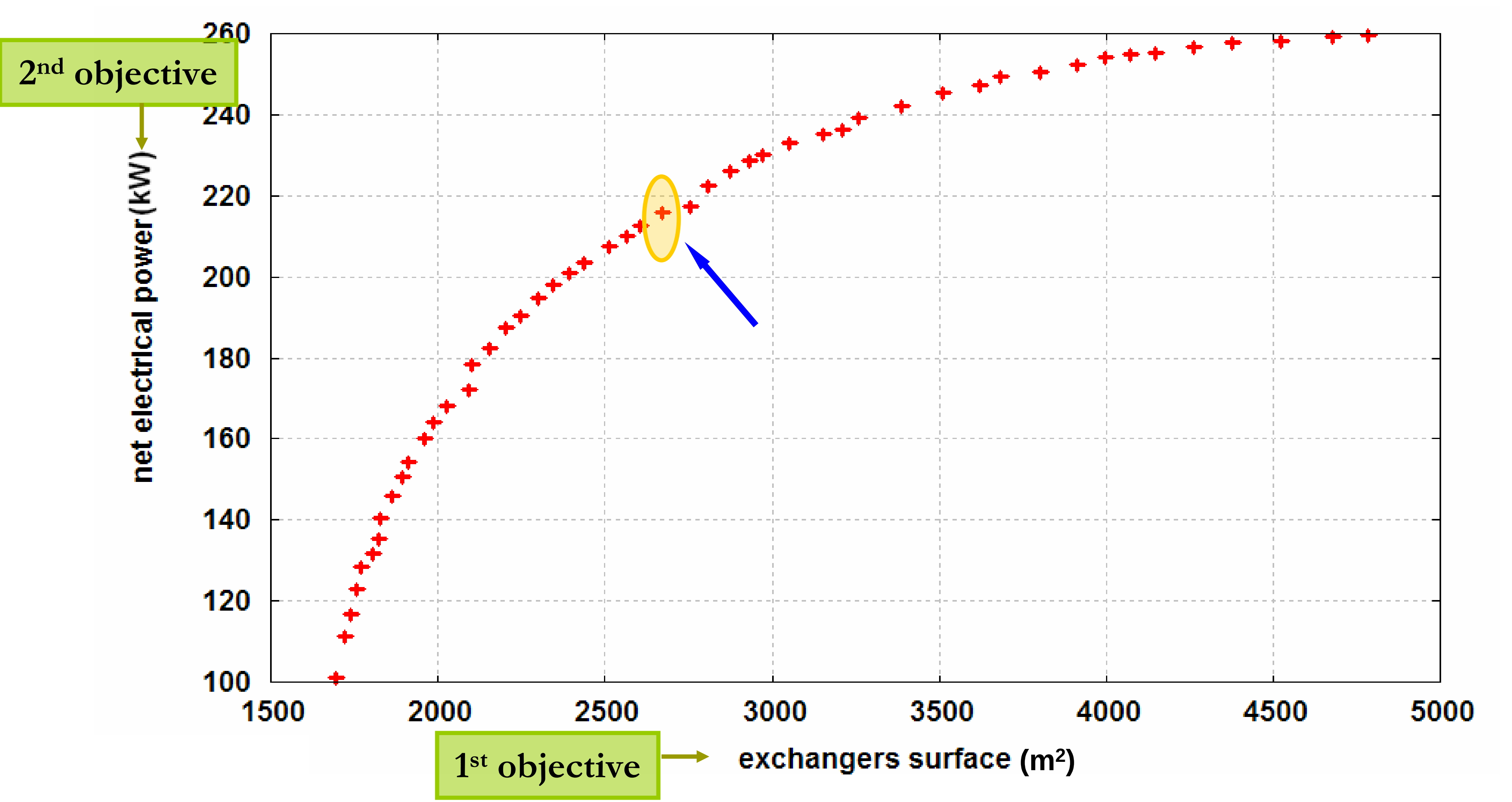
using the EASY software code (Evolutionary Algorithm System) by National Technical University of Athens
http://velos0.ltt.mech.ntua.gr/EASY

ORC with temperature threshold of 80°C



ORC with temperature threshold of 80°C

Optimal solutions



ORC with temperature threshold of 80°C

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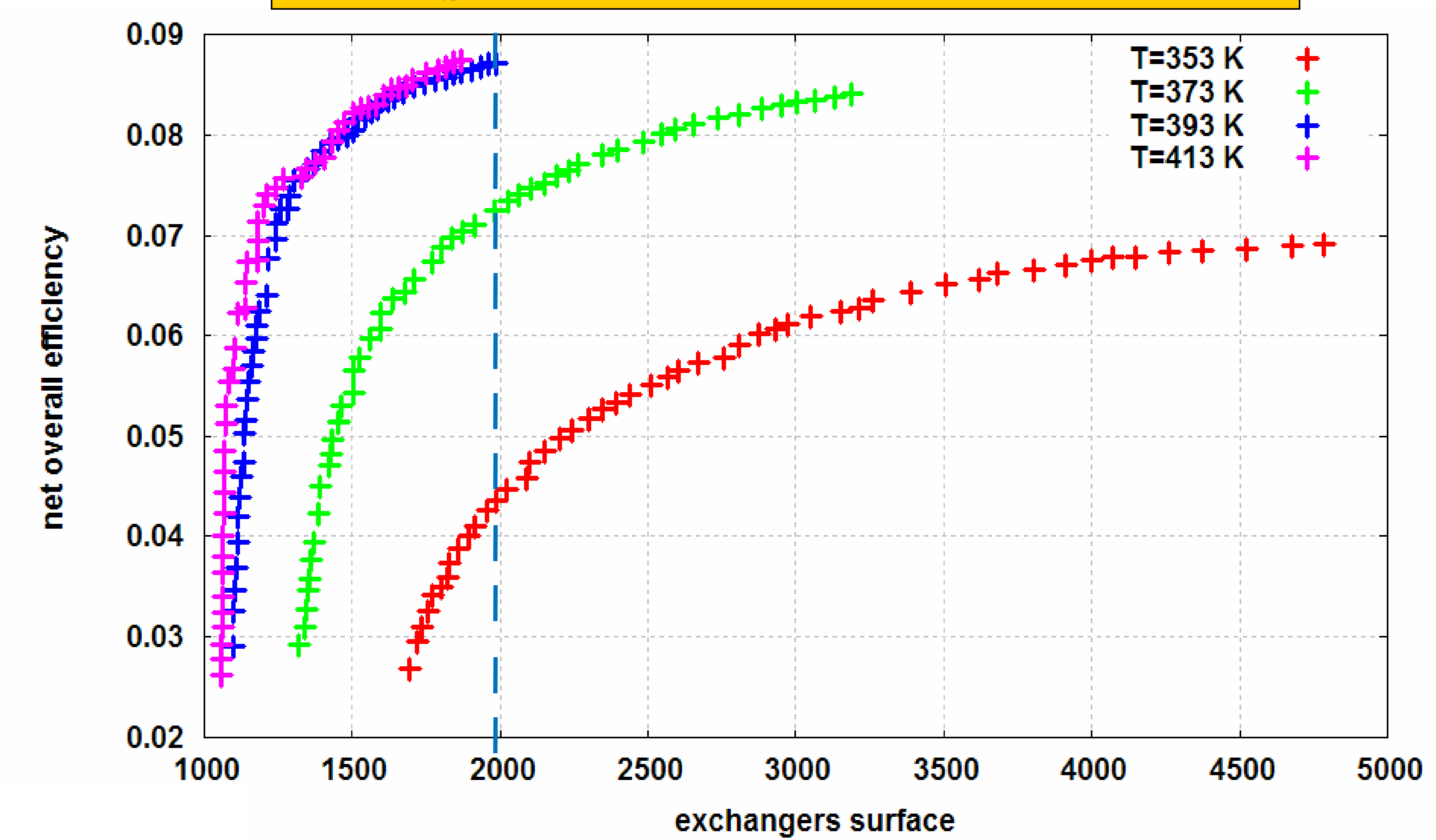
Parameter	Value
p_2 (kPa)	1876
m_{gr} (kg/sec)	60
m_{R134a} (kg/sec)	18.5
ΔT_H (°C)	15
ΔT_C (°C)	5
R134a pump power (kW)	30
Cooling water flow (kg/sec)	164.5
Surface of the condenser (m^2)	2158
Surface of the heat exchanger (m^2)	597
Total H.E. surface (m^2)	2755
Net conversion efficiency	5.77
Net Electrical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

Comparison between different temperature thresholds

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



Comparison between different temperature thresholds

Variable	T = 80ºC	T = 100ºC	T = 120ºC	T = 140ºC
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

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