“GEOTHERMAL BINARY PLANTS: WATER OR AIR COOLED ?”

by

D.Mendrinos, E.Kontoleontos, C.Karytsas

Centre for Renewable Energy Sources

Geothermal Power Plants

- Back pressure flash plants
- Condensing flash plants
- Binary plants

Cooling Options

- (water cooled condensers) & (surface water)
- (water cooled condensers) & (wet type cooling towers)
- (air cooled condensers) & (dry type cooling towers)

Carnot Efficiency

$$n = \frac{Tg - Tc}{Tg}$$

- "*Tg*": geothermal source temperature, °K
- "*Tc*": cooling water temperature, °K

Turbine Efficiency

$$w = n_t \cdot m \cdot (H_s - H_o)$$

$$N = n_g \cdot w$$

$$n = \frac{N}{m \cdot H_s} = \frac{n_g \cdot n_t \cdot (H_s - H_o)}{H_s}$$

- *n: overall conversion efficiency*
- *n_g: generator efficiency*
- *n_t: turbine efficiency*
- *H_s: vapour specific enthalpy at turbine inlet*
- *H_o: vapour specific enthalpy at turbine outlet*
- *m: fluid mass flow*

Water vs. Air cooled condensers

property	water	air
Specific heat, kJ / kg^oC	$c_{pw} = 4{,}19$	$c_{pa} = 1{,}00$
Density, kg/m^3	ρ_w=999	ρ_a=1,2
Volumetric Heat Capacity, $kJ / m^{3o}C$	$VHC_w = 4182$	$VHC_a = 1{,}21$
Heat transfer coefficient $kW / m^{2o}C$	$h_w = 4{,}84$	$h_a = 0{,}084$

Binary Plant Economics

- Heat Exchangers
- H.E. surface
- weight

Cooling with Surface Water

- 5 – 25 °C ⇒
- lowest condensing temperature: 15-35 °C
- 970 t/h per MW_e for $\Delta T = 10$ °C
- Shell & Tube Condenser
  - *cross flow, double pass*
- Plate H.E. as condenser
  - *10-20 kW_{th}/m^2 for $\Delta T = 5$ °C*
  - *easy to clean*

Cooling with Surface Water

- Lower than ambient T in Summer
- Do not froze in Winter
- No cooling towers
- Cogeneration possibility

Cooling with Surface Water

- Need for large water quantity
- Fooling or corrosion
- Need to transport water

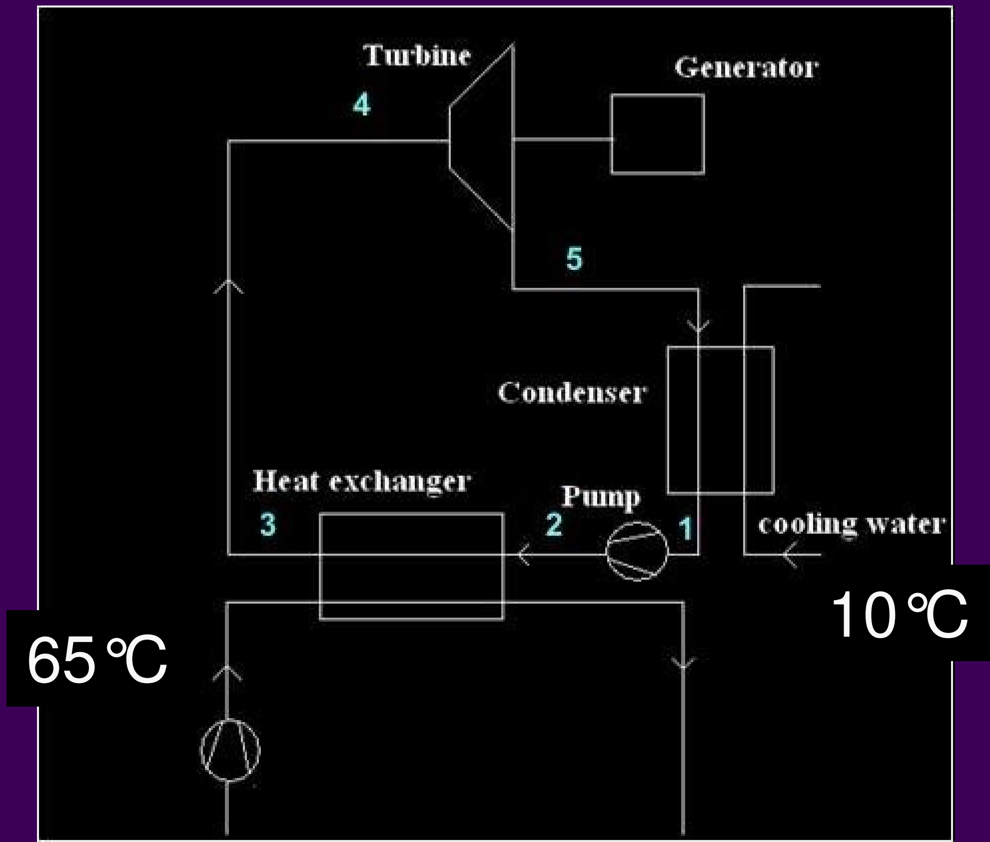
Wet Type Cooling Towers

- Mechanical draft (fan)
- Cool water loop with $\Delta T \sim 10°C$
- Deliver >25°C
- 40°C condensing temperature
- 30 t/h per MW_e of make-up water
  - *evaporation & blowdown*
- Flash Plants
  - *direct contact condensers*

Dry Type Cooling Towers

- Mechanical draft (fans)
- Deliver ambient temperature air
- 40-50℃ condensing temperature
- No need for make-up water
- Most expensive option:
  - *5-10 times more costs than wet type*
  - *20-50% higher binary plant costs*
- The only option in case of water scarcity or cold climatic extremes

R134a Rankine Cycle Optimization (LOW-BIN project)



using the EASY software code (Evolutionary Algorithm System)

by National Technical University of Athens, ref. http://velos0.ltt.mech.ntua.gr/EASY

Modeling the Condenser

Overall heat transfer:

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

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 in tubes:

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

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

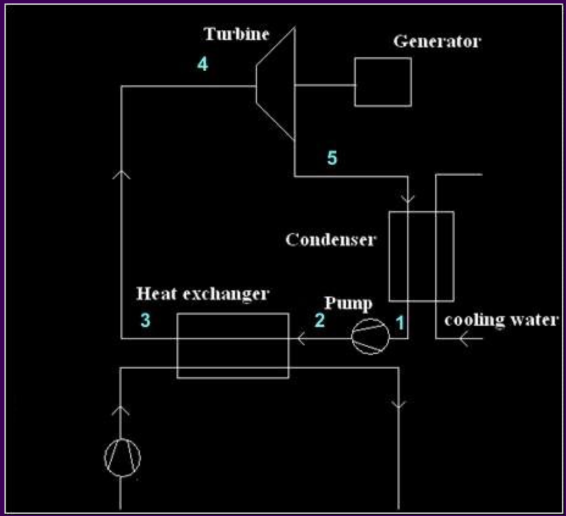
Optimization Variables

variable	min	max
R134a pump discharge pressure P_2, bar	7,5	12,0
Geothermal water mass flow m_{gr}, kg/s	45	55
R134a mass flow m_{134a}, kg/s	10	20
Geothermal water ΔT_H, ℃	10	30
Cooling water ΔT_C, ℃	7,5	12,5

Optimization Objectives

- Maximum conversion efficiency

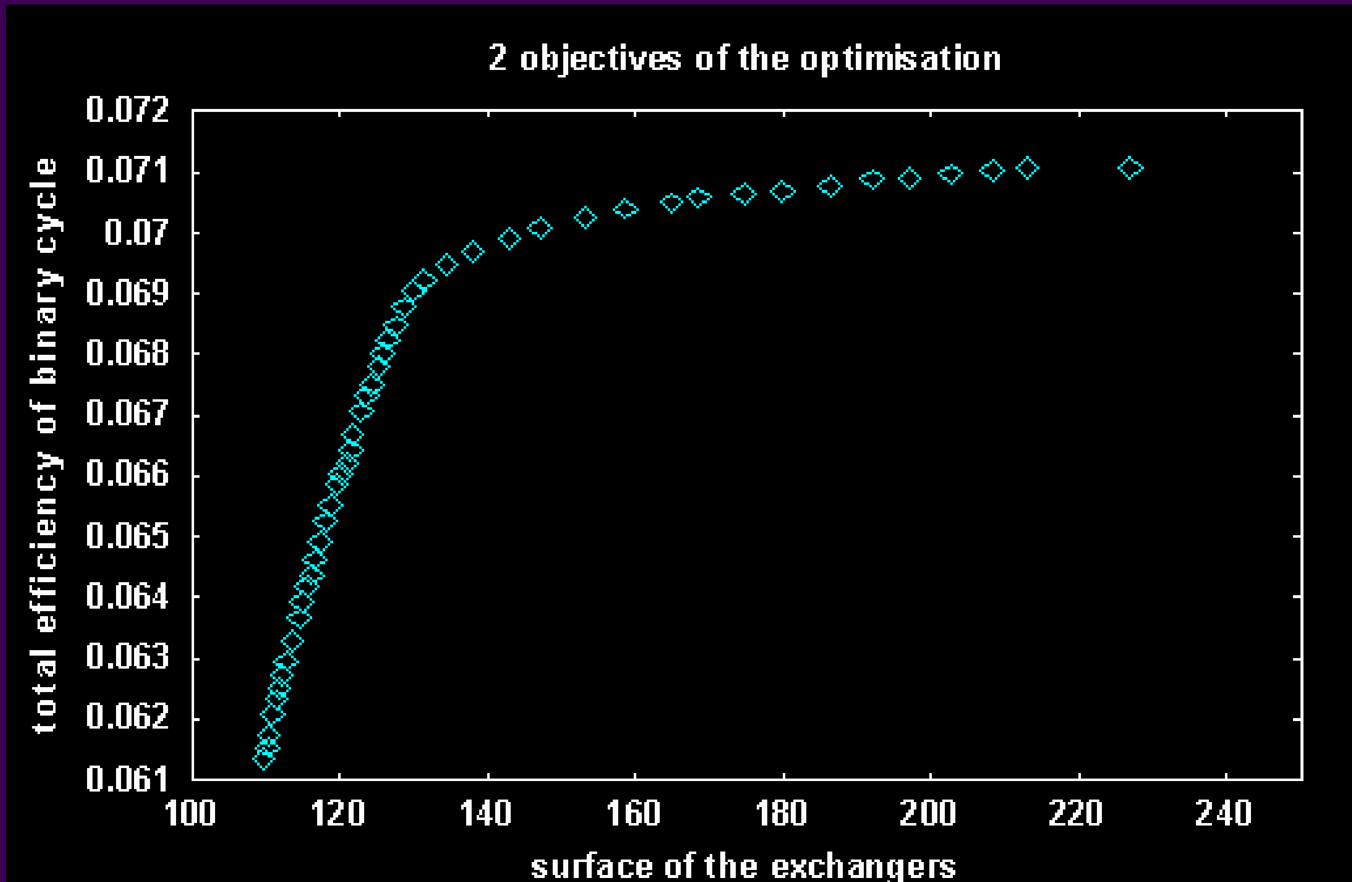
$$\eta_{cycle} = \frac{w_{turbine}}{q_{heatexch}} = \frac{h_4 - h_5}{h_3 - h_2}$$



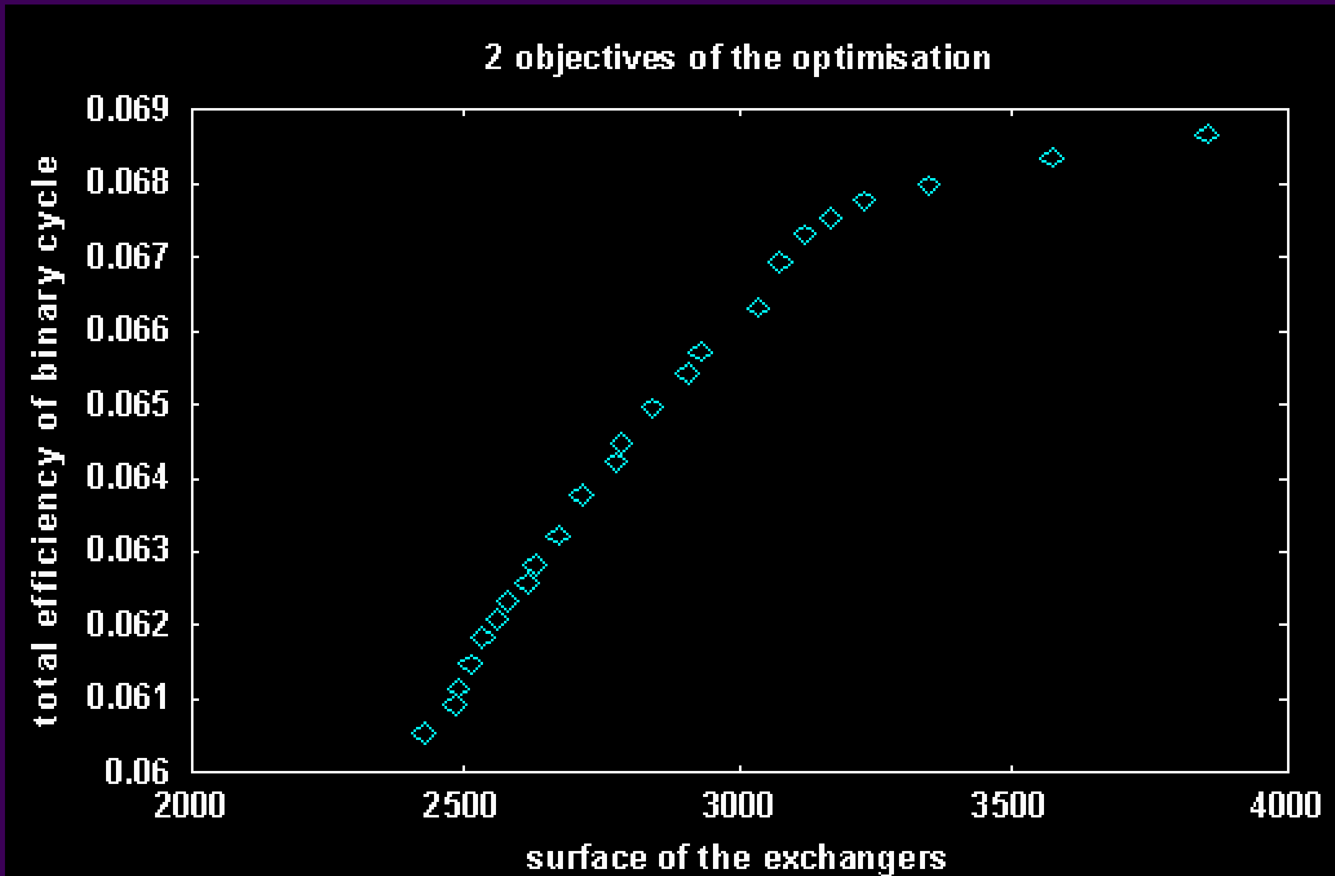
- Minimum costs

$\Rightarrow$ *minimum heat exchange surface*

Water Cooled Rankine Cycle



Air Cooled Rankine Cycle



Water vs. Air Cooled

variable	Water cooled	Air cooled
$P_{2\text{-}R134a}$ (bar)	11	11
m_{gr} (kg/sec)	52,3	53,0
m_{134a} (kg/sec)	17,5	17,5
ΔT_H (°C)	17,5	17,8
ΔT_C (°C)	7,5	7,5
R134a pump power (KW)	13	12
cooling fluid flow (m^3/h)	403	$3{,}45 \cdot 10^5$
Overall heat transfer coefficient U	5580	102
Surface of the condenser (m^2)	88	3160
Total H.E. surface (m^2)	138	3230
Conversion Efficiency	6,96 %	6,78 %

Conclusions

- Cooling improves conversion efficiency

- Binary Plants:

Efficiency ↓ , Costs ↑, Water needs ↓ for:

Cooling with surface water

⇓

Wet type cooling towers

⇓

Dry type cooling towers