**4EM70 A.2 Binary CHP plant – base design**

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**PLEASE USE THE FOLLOWING NOTATION:**

* express values in the units as given in the tables
* separate the [integer](https://en.wikipedia.org/wiki/Integer) part from the [fractional](https://en.wikipedia.org/wiki/Fraction_(mathematics)) part of a [number](https://en.wikipedia.org/wiki/Number) by a **dot**; e.g. “4.56”
* use **“e”** to express powers of 10 in scientific notation; e.g. “4.6e3”
* separate multiples of 1000 etc by **spaces**; e.g. 3 467 176

**A.2.1 Heat-only plant**

**1 Calculated return water temperature:** 28.62 °C

**2 Counterflow Ducts Heat Exchanger:**

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| Counterflow offers the most optimal heat exchanging coefficients without requiring any correction factors. Using alternating hot and cold flow through the ducts in the vertical and horizontal direction, the heat exchanging surface is optimized (compared to e.g. alternating hot and cold flow through wide ‘plates’). The massflows are similar, so flow velocity for both flows is within the accepted range |

**3 Capacity flow ratio:** 1

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| Higher CR means higher massflow in well  Results in higher velocity & higher heat transfer coef.?  NTU and effectiveness unchanged..? hier hadden we mooie plotjes voor toch? |

**4 Well water return temperature:** 158.62 °C

Well water mass flow: 137.43 kgs-1

**5 Logarithmic mean temperature difference:** 130 °C

**6 Heat exchanger design**

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| --- | --- | --- |
| **Counterflow Ducts HX** | **Well side** | **District Heating** |
| Inlet temperature °C | 240 | 28.62 |
| outlet temperature °C | 158.62 | 110 |
| heat transferred kW | 50 000 | |
| logarithmic mean temperature difference °C | 130 | |
| mass flow kgs-1 | 137.43 | 146.73 |
| average heat capacity Jkg-1K-1 | 4 470.86 | 4 187.55 |
| capacity flow WK-1 | 6.1443e5 | 6.1443e5 |
| average or bulk velocity ms-1 | 1.17 | 1.11 |
| average density kgm-3 | 868.08 | 978.19 |
| average dynamic viscosity Pa s | 1.357e-4 | 4.078e-4 |
| hydraulic diameter m | 0.020 | 0.020 |
| Reynolds number | 1.498e5 | 5.323e4 |
| average heat conductivity Wm-1K-1 | 0.667 | 0.659 |
| Nusselt number | 307.5 | 193.8 |
| heat transfer coefficient Wm-2K-1 | 1.03e4 | 6.39e3 |
| overall heat transfer coefficient Wm-2K-1 | 3 648.15 | |
| number of transfer units (NTU) | 0.626 | |
| effectiveness () | 0.3850 | |
| capacity flow ratio (CR) | 1 | |

**7 Heat exchanging surface:** 105.43 m2

**8 Investment for heat production**

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| --- | --- |
| heat retail price US$/kWh | 0.03 |
| heat exchanger installed costs | 76 160.82 |
| installed costs per kWh heat produced US$/kWh | 1.523 |
| payback time in hours | 50.774 |

**A.2.2 Power cycle**

**1 Condensor pressure:** 2 bar

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| Keep it low 🡪 just above DH line to ensure sufficient residual heat  optimize electricity production by moving point 5 to the left |

**2 Pressure in the steam generator:** 15.55 bar

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| As high as possible 🡪 just below Well line to ensure sufficient heat can be transferred  Optimize eletricity production by moving point 4 to the right |

**3 State variables and heat/work exchange**

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| --- | --- | --- | --- | --- | --- | --- |
|  | bar | °C | kJkg-1 | kJkg-1K-1 | kJkg-1 | kJkg-1 |
| 1 saturated liquid (condensor heat) | 2 | 120.21 | 504.68 | 1.5301 | -1927.6 | X |
| 2 compressed liquid (pump work) | 15.55 | 120.33 | 506.14 | 1.5301 | X | -1.45 |
| 3 saturated liquid (economizer heat) | 15.55 | 200 | 852.39 | 2.3308 | 346.25 | X |
| 4 saturated vapour (evaporator heat) | 15.55 | 200 | 2 792.1 | 6.4303 | 1 939.7 | X |
| 5 wet steam (turbine work) | 2 | 120.21 | 2 432.2 | 6.4303 | X | 359.82 |

**4 steam mass flow:** 25.94 kgs-1

**6 steam quality @ turbine exit:** 0.8755

**7 thermal efficiency:** 0.1568

**8 Power output:** 9.33 MW

**9 Economizer design**

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| **Shell and Tube HX** | **Well side** | **Rankine side** |
| Inlet temperature °C | 208.89 | 120.33 |
| outlet temperature °C | 203.19 | 200 |
| heat transferred kW | 8 981.70 | |
| logarithmic mean temperature difference °C | -33.14 | |
| mass flow kgs-1 | 350 | 25.94 |
| average heat capacity Jkg-1K-1 | 4 505.60 | 4 335.07 |
| capacity flow WK-1 | 1.5770e6 | 1.1245e5 |
| average or bulk velocity ms-1 | 1.32 | 1.21 |
| average density kgm-3 | 860.07 | 907.85 |
| average dynamic viscosity Pa s | 1.310e-4 | 1.703e-4 |
| hydraulic diameter m | 0.0369 | 0.020 |
| Reynolds number | 3.1921e5 | 1.2930e5 |
| average heat conductivity Wm-1K-1 | 0.6622 | 0.6824 |
| Nusselt number | 559.1 | 290.4 |
| heat transfer coefficient Wm-2K-1 | 1.00e4 | 9.91e3 |
| overall heat transfer coefficient Wm-2K-1 | 4 314.95 | |
| heat transferring surface m2 | 62.81 | |
| number of transfer units (NTU) | 2.41 | |
| effectiveness () | 0.900 | |
| capacity flow ratio (CR) | 0.0713 | |

**10 Evaporator design**

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| **Counterflow Ducts HX** | **Well side** | **Rankine side** |
| Inlet temperature °C | 240 | 200 |
| outlet temperature °C | 208.89 |
| heat transferred kW | 50 314.17 | |
| logarithmic mean temperature difference °C | -20.68 | |
| mass flow kgs-1 | 350 | 25.94 |
| average heat capacity Jkg-1K-1 | 4 620.76 | - |
| capacity flow WK-1 | 1.6173e6 |  |
| average or bulk velocity ms-1 | 1.31 | - |
| average density kgm-3 | 836.74 | - |
| average dynamic viscosity Pa s | 1.1963e-4 | - |
| hydraulic diameter m | 0.020 | - |
| Reynolds number | 1.8285e5 | - |
| average heat conductivity Wm-1K-1 | 0.6469 | - |
| Nusselt number | 352.8 |  |
| heat transfer coefficient Wm-2K-1 | 1.14e4 |  |
| overall heat transfer coefficient Wm-2K-1 | 9 290.29 | |
| heat transferring surface m2 | 261.82 | |
| number of transfer units (NTU) | 1.504 | |
| effectiveness () | 0.778 | |
| capacity flow ratio (CR) | 0 | |

**11 Condensor design**

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| **Counterflow Ducts HX** | **District Heating** | **Rankine side** |
| Inlet temperature °C | 28.62 | 120.21 |
| outlet temperature °C | 110 |
| heat transferred kW | 50 000 | |
| logarithmic mean temperature difference °C | 37.09 | |
| mass flow kgs-1 | 146.73 | 25.94 |
| average heat capacity Jkg-1K-1 | 4 187.5 | - |
| capacity flow WK-1 | 6.1443e5 |  |
| average or bulk velocity ms-1 | 1.30 | - |
| average density kgm-3 | 978.19 | - |
| average dynamic viscosity Pa s | 4.0775e-4 | - |
| hydraulic diameter m | 0.02 | - |
| Reynolds number | 6.2474e4 | - |
| average heat conductivity Wm-1K-1 | 0.6591 | - |
| Nusselt number | 220.3 |  |
| heat transfer coefficient Wm-2K-1 | 7.259e3 |  |
| overall heat transfer coefficient Wm-2K-1 | 6 338.89 | |
| heat transferring surface m2 | 212.64 | |
| number of transfer units (NTU) | 2.194 | |
| effectiveness () | 0.889 | |
| capacity flow ratio (CR) | 0 | |

**12 Additional investment for electricity production**

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| electricity retail price US$/kWh | 0.09 |

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| --- | --- |
| pump installed costs US$ | 18 304.81 |
| turbine/condensor installed costs US$ | 1 293 076.25 |
| economizer installed costs US$ | 69 618.11 |
| evaporator installed costs US$ | 373 721.55 |
| total installed costs | 1 754 720.72 |

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| additional costs for electricity production US$ | 1 678 559.90 |
| additional installed costs per kWh work produced US$/kWh | 179.8405 |
| payback time in hours | 1 998.23 |

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| Pinch diagram for entire CHP plant (include saturation curve) |