Potential performance of environmental friendly application of ORC and Flash technology in geothermal power plants

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INTRODUCTION

Context
• Geothermal power plants temperature range of 150-200°C

Objective
• Definition and simulation of environmental friendly geothermal plants evaluating the performances
• Effect of concentration of the CO₂ on the performances of the two scheme of plants

Methodology
• Bibliographic review for experimental data for validation of the thermodynamic model for the geothermal fluid
• Aspen Plus simulations of the geothermal plants
Overview on geothermal fluids

The chemical composition of the geothermal fluid is strongly site dependent (water, salts, gases).

Main gas: CO$_2$
Other gases: H$_2$S, hydrocarbons, N$_2$, H$_2$...

Case of Italy: sites with non-condensable gas content from 4 to 10% by weight

The concern for “climate change” encourages the investigation of possible power plant schemes which do not release CO$_2$ in the atmosphere.
**Main technologies – binary systems**

**Geothermal fluid 100 °C- 160 °C (and higher)**
advantage, geothermal fluid in a closed loop

Common configuration of binary cycle technology is equipped with submersible pump that can guarantee a stable well production, but that is subjected to scaling, cavitation that determine a short lifespan.
Geothermal fluid > 160 °C

In the traditional flash plant layout non-condensable gases are extracted from the condenser,

The main feature of this technology is the adoption of a direct cycle, whereby the geothermal fluid coming from wellhead is flashed, and separated steam enters a steam turbine, followed by a condenser.

The gas collected at the condenser are at low pressure: they are recompressed at higher pressure
Thermodynamic properties of the geothermal fluid

This work focusses on the CO\textsubscript{2} issue, and therefore only the carbon dioxide is considered as non-condensable gas present in the geothermal fluid.

The **thermodynamic model** adopted to study the performances of the plants is validated with experimental results available in literature.

The thermodynamic model that better performs is the Electrolyte-NRTL, it considers the carbonic chemical equilibrium.
Simulation of the Reservoir

The well-reservoir flow is simulated considering a horizontal mass flow in a porous medium, followed by a vertical flow in a pipe, under steady conditions.

**Pressure difference** between an undisturbed point in the reservoir and the well feed is expressed by

\[
C_D = \frac{\Delta p}{m}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawdown coefficient</td>
<td>$C_D$</td>
</tr>
<tr>
<td>Reservoir pressure</td>
<td>$p_{\text{res}}$</td>
</tr>
<tr>
<td>Well depth</td>
<td>$L$</td>
</tr>
<tr>
<td>Well diameter</td>
<td>$D$</td>
</tr>
</tbody>
</table>

The correlations of Beggs-Brill good results, it is quite largely adopted in geothermal applications.
Simulation of zero emission Flash Plant

Description of the component
- CMP: compressor
- CND: condenser
- DEM: demister
- FL: flash
- HX: heat exchanger
- MX: mixer
- PMP: pump
- RES: reservoir
- SEP: separator
- TRB: turbine
- WELL: well
Binary plant (ORC)

Description of the component
- **CND**: condenser
- **ECO**: economizer
- **EVA**: evaporator
- **PMP**: pump
- **RES**: reservoir
- **SEP**: separator
- **TRB**: turbine
- **WELL**: well

**Production well**
- **WELL1**: Submersible pump

**Reinjection well**
- **WELLRJT**: Submersible pump
**n-Pentane** (flammable fluid).

\( T_{Cr}: 196.5 \, ^\circ C; \quad P_{Cr}: 33.7 \, \text{bar} \quad \text{MW: 72.2 g/mol} \)

**HCFO-1233zd(E)** trans-1-chloro-3,3,3-trifluoropropene

\( T_{Cr}: 165.6 \, ^\circ C; \quad P_{Cr}: 35.7 \, \text{bar} \quad \text{MW: 130.5 g/mol} \)

It is environmentally friendly: GWP = 5; non-flammable.

According to preliminary investigation, it seems thermally stable at least up to nearly 200 \(^\circ C\).
Thermodynamic cycles

Example of saturated cycles
max pressure of 12 bar
min temperature of 32 °C

n-Pentane

Pmin: 0.85 bar

HCFO-1233zd(E)

Pmin: 1.6 bar
Basic assumptions for the parametric analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature</td>
<td>15 °C</td>
</tr>
<tr>
<td>Condenser cooling medium</td>
<td>Water</td>
</tr>
<tr>
<td>Turbine isentropic efficiency</td>
<td>0.9</td>
</tr>
<tr>
<td>Pump hydraulic efficiency</td>
<td>0.8</td>
</tr>
<tr>
<td>Organic-electric efficiency</td>
<td>0.95</td>
</tr>
<tr>
<td>CO₂ mixing pressure</td>
<td>80 bar</td>
</tr>
<tr>
<td>Condensing temperature</td>
<td>32°C</td>
</tr>
<tr>
<td>Heat rejection electric consumption</td>
<td>0.01 MWₑ·MWₑ⁻¹</td>
</tr>
</tbody>
</table>

Performance evaluation

- Reservoir temperature (150°C, 175°C and 200°C)
- CO₂ content (0%, 1% and 5%)
### Results Flash plant with CO$_2$ recovery

**Mass flow rate** (productivity of the well)
Pressure drop at “pre-flash”: 1%

**A parametric analysis**
**Pressure at the flash** chamber before the turbine

<table>
<thead>
<tr>
<th>$200 , ^\circ C$</th>
<th>CO$_2$ conc.</th>
<th>0%</th>
<th>1%</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{Wh}$, bar</td>
<td>2.3</td>
<td>9.2</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>$m_W$, kg/s</td>
<td>93</td>
<td>80</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>$P_{aux}$, MWe</td>
<td>0.74</td>
<td>5.4</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>$Q_{cond}$, MW$_{th}$</td>
<td>33.5</td>
<td>16.4</td>
<td>23.3</td>
<td></td>
</tr>
<tr>
<td>NetP, MWe</td>
<td>4.9</td>
<td>2.0</td>
<td>2.6</td>
<td></td>
</tr>
</tbody>
</table>
Results Binary plants

**Mass flow rate** (max of pump: 200 l/s)

**ΔT**\(_{\text{min}}\)** at heat exchangers: 10 °C

A parametric analysis

**Pressure of the cycle** maximization of power production

**CO\(_2\)** concentration: not possible exceed 1% because of cavitation

<table>
<thead>
<tr>
<th>200 °C</th>
<th>HCFO1233zd(E)</th>
<th>n-Pentane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO(_2)</strong> conc.</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>(m_{\text{ORC}}), kg/s</td>
<td>547</td>
<td>488</td>
</tr>
<tr>
<td>(T_{\text{max ORC}}), °C</td>
<td>153</td>
<td>153</td>
</tr>
<tr>
<td>(P_{\text{max ORC}}), bar</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>(Q_{\text{cond, MW}_{\text{th}}})</td>
<td>112</td>
<td>104</td>
</tr>
<tr>
<td>NetP, MWe</td>
<td>21.6</td>
<td>19.3</td>
</tr>
</tbody>
</table>
Comparisons of results

Organic Rankine Cycle reach higher values, but the CO$_2$ content is a limitation in case of use of a pump in the well.
Conclusions and future works

Conclusions

The **performance** of investigated layout are highly affected by the concentration of the **carbon dioxide** present in the reservoir. In general:

- Submersible pump has good effect on power production
- Presence of CO\(_2\) decrease the power production
- Flash plants can handle wide range of CO\(_2\) concentration
- HCFO-1233zd(E) is a possible option for geothermal application

Future works

- Presence of salts in geothermal fluid
- **Flash**: recovery of heat duty of the CO\(_2\) compression; separated reinjection of CO\(_2\); 2 pressures level.
- **ORC**: other scheme of plants (2 pressure levels)
- Techno-economic analysis