Optimization of an Organic Rankine Cycle Power System Using Mid-low Temperature Geothermal Water

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Abstract. In order to effectively utilize geothermal resources at mid-low temperatures, an Organic Rankine cycle (ORC) system was used to establish a thermodynamic model. The working fluid of R245FA was analyzed and evaluated to determine the higher efficiency of the system. With evaporation temperature, geothermal temperature and cooling water temperature as key performance indicators, the system was employer and its efficiency influenced factors were studied. From the results we know that for the ORC system, when the geothermal water temperature reaches 373K and other input parameters are typical values, the total PPH of ORC system is 7.5.

1. Introduction

Geothermal energy is a gift from nature. It is a huge natural energy contained in the earth. It has become one of the most important renewable energy sources in the development of energy in the new century. It is also one of the most realistic and competitive of renewable energy [1].

The remarkable feature of the distribution of geothermal resources in China is that it is mainly mid-low-temperature geothermal. Therefore, it is necessary to explore low-temperature geothermal power generation technology while high-temperature geothermal power generation is limited [2-3]. The application and promotion of ORC and other dual-cycle technologies make the mid-low temperature geothermal resources of 80~150°C also have the possibility and economy of power generation utilization, which makes the temperature of geothermal resources that can generate electricity economically gradually decrease. In recent years, many researchers have done a lot of work about organic Rankine cycle geothermal power generation systems [4-6].

In this paper, the ORC power generation system with subcritical saturated steam is selected as the research object. The cycle optimization method with “PPH” as the optimization target is proposed, and the performance of the ORC system is analyzed. And the key factors of economic performance: the best evaporation temperature and the temperature of the cold and geothermal sources.

2. System design
Figure 1. Flow chart of the ORC system

1. pre-heater 2. evaporator 3. Turbine generator 4. Condenser 5. Circulating pump

As shown in Figures 1 and 2, the ORC system studied in this paper consists of two cycles. Its working principle is as follows: the working fluid in the evaporator is heated and evaporated by geothermal water at low boiling point to produce high temperature and high pressure steam, then the working fluid flowed into the turbine to driven generator for power generation. Then the working fluid enters the condenser and will be cooled to low temperature and low pressure liquid in the condenser.
Afterwards, the cooled working fluid in the condenser is pumped back to the evaporator, where it evaporates again to complete the cycle.

3. Thermodynamic analysis

In order to simplify the thermodynamic model, we make the following assumptions: the components in the system are steady-state flow, and the state is considered stable; the heat loss and friction loss of ORC system can be neglected.

For ORC:

\[
\begin{align*}
  m_g (h_{g1} - h_{g2}) &= m_o (h_3 - h_1) \\
  m_g (h_{gp} - h_{g2}) &= m_o (h_2 - h_1) \\
  m_g (h_{g1} - h_{gp}) &= m_o (h_3 - h_2) \\
  P &= m_g (h_3 - h_4) \eta_w \eta_g = m_o (h_3 - h_{as}) \eta_g \eta_m \eta_g \\
  m_o (h_{as} - h_{4}) &= m_o (h_4 - h_5) \\
  W_p &= m_o (h_1 - h_3) = m_o (h_{is} - h_5)/\eta_p
\end{align*}
\]

The overall performance of ORC:

\[
P_{net} = P - W_p
\]

\[
PPH = P_{net}/m_g
\]

\[
\eta_t = \frac{P_{net}}{Q_P + Q_E} = \frac{P - W_p}{m_g (h_{g1} - h_{g2})}
\]

4. Results and discussion

The input parameters and boundary conditions were given in Table 1. The thermal and mechanical properties of ORC system under different working conditions were simulated by using the computer program compiled by EES (Engineering Equation Solver). The analysis results are shown in Fig. 3-5. At the same time, it is also noted that other input data of the system are the same as the typical values given in Table 1. It is only discussed that the parameters affecting the efficiency of the system are different in the range of values.

| Table 1. Boundary conditions and input parameters |
|-----------------------------------------------|
| Parameter                        | Typical value | Ranges       |
|-----------------------------------------------|
| Mass flow rate of geothermal water         | 20kg/s        | —            |
| geothermal temperature                 | 373K          | 353K-393K    |
| Evaporation temperature                 | 333K          | 326K-353K    |
| Cooling water temperature               | 298K          | —            |

Figure 3 shows the effect of geothermal water temperature on PPH and \( \eta_t \). It can be seen that the PPH of ORC system increases with the increase of geothermal water temperature. When the geothermal water temperature is 373K, the maximum PPH of the system is 7.5 as the higher critical temperature of organic matter. Fig. 3 also shows that \( \eta_t \) generally increases with the increase of geothermal temperature. The maximum temperature of R245fa case is 0.048 at 373K.
Since the cooling water temperature has an effect on both cycles, so the condensation temperature has a significant effect on the performance of ORC system, as shown in Figure 4. In order to achieve good efficiency in both cycles, it is not usually desirable that the cooling water temperature is too high, because the total heat exhaust is determined by the cooling water temperature. Also, it can be seen...
from Fig. 4 that when the cooling water temperature rises, PPH and $\eta_t$ decreases. Under the same operating conditions, the minimum $\eta_t$ value of ORC is 0.039, the maximum value is 0.074.

Fig. 5 shows the effect of evaporation temperature on PPH and $\eta_t$. It can be found that with the increasing of evaporation temperature, the PPH of ORC also increases, but when the evaporation temperature reaches 341K, the PPH of ORC system begins to decrease. Under the same operating conditions, the minimum PPH value of ORC is 5.27, and the maximum PPH value of ORC is 7.5. And $\eta_t$ of ORC system increases almost linearly. When the evaporation temperature increases from 326K to 353K, the $\eta_t$ increases by about 140%.

Figure 5. Effect of evaporation temperature on PPH and $\eta_t$

5. Conclusion
In order to make full use of mid-low geothermal temperature resources, this paper establishes a thermodynamic model of ORC system using R245FA as working fluid, and analyses the influence of geothermal water temperature, condensation temperature and evaporation temperature on the system performance. The results show that PPH and $\eta_t$ will increase with the increasing of geothermal water temperature, and the opposite is real for condensation temperature. When the geothermal water temperature is 373K and other input parameters are typical values, the PPH of ORC is 7.5. The theoretical analysis results show that it is feasible for ORC system to generate geothermal power at mid-low temperature.

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References
[1] R. Bertani. Geothermal Power Plant in the World 2005-2010 Update Report. Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April, 2010, paper no. 0008
[2] Bombarda, P., Gaia, M. Geothermal Binary Plants Utilising an Innovative Non-Flammable Azeotropic Mixture as Working Fluid. Proceedings 28th NZ Geothermal Workshop 2006
[3] Borsukiewicz-Gozdur, W. Comparative analysis of natural and synthetic refrigerants in application to low temperature Clausius-Rankine cycle, Energy, 2007, 32, 344-352

[4] Hettiarachchi, Golubovic, M., Worek, W. M., et al. Optimum design criteria for an Organic Rankine cycle using low-temperature geothermal heat sources. Energy, 2007, 32, 1698-1706

[5] Yamamoto, T., Furuhata, T., Arai, N., et al. Design and testing of the Organic Rankine Cycle. Energy, 2001, 26, 239-251

[6] Kanoglu, M., Bolatctturk, A. Performance and parametric investigation of a binary geothermal power plant by exergy. Renewable Energy, 2008, 33, 2366-2374