

Utilization of Hot Springs in Oman for Sustainable Electricity Generation

Narjis Al Abri

abunares2009@gmail.com

Abstract: This study investigates the feasibility of utilizing naturally occurring hot springs in Oman as a sustainable source of electricity generation. Oman's electricity sector is still largely dependent on natural gas, creating long-term concerns related to energy security and environmental sustainability. Several hot spring locations, including Al Kasfah Hot Spring and Nakhl Hot Springs, provide continuous geothermal water flow with moderate temperatures that can be exploited using low-temperature geothermal technologies.

The research proposes an integrated system that utilizes thermal energy, kinetic energy from water flow, and low-pressure steam to generate electricity. The primary technology considered is the binary cycle system, particularly the Organic Rankine Cycle (ORC), which is well suited for low-enthalpy geothermal resources. A hybrid configuration combining heat exchangers, micro-hydraulic turbines, and compact steam turbines is suggested to maximize energy recovery.

Environmental analysis indicates that geothermal power derived from hot springs has a very low carbon footprint, especially when reinjection

strategies are applied to maintain reservoir sustainability and protect natural ecosystems (DiPippo, 2016). Economically, small-scale modular systems are shown to be attractive due to

relatively low operating costs and the absence of fuel requirements (Lund & Boyd, 2016). The study also highlights the importance of regulatory frameworks, environmental impact assessments, and community engagement in ensuring successful project implementation.

The results demonstrate that hot spring-based electricity generation can contribute to national energy diversification strategies, reduce greenhouse gas emissions, and support decentralized power supply in rural and touristic regions. The study concludes that geothermal energy from hot springs represents a promising and underutilized renewable resource for Oman's future sustainable energy development.

1. Introduction and Background

The rapid increase in global electricity demand and the negative environmental impacts of fossil fuels have encouraged many countries to adopt renewable energy technologies. Oman has already made significant progress in solar and wind energy development; however, geothermal energy remains largely unexplored.

Hot springs in Oman are naturally heated groundwater systems that emerge due to geothermal

gradients and geological structures. These springs provide a stable and continuous thermal source, making them suitable for renewable electricity production. According to International Renewable Energy Agency, diversification of renewable energy resources plays an essential role in improving energy security and sustainability in the Gulf region (IRENA, 2020).

2. Geothermal Potential of Hot Springs in Oman

Several hot spring sites across northern Oman exhibit water temperatures that are suitable for low-temperature geothermal applications. Al Kasfah and Nakhl hot springs are among the most prominent locations, characterized by stable discharge and year-round availability.

Although the temperature of these resources is lower than that of conventional geothermal fields, they can be efficiently exploited using binary cycle power technologies (Lund & Boyd, 2016). The distributed nature of hot springs also allows for decentralized electricity production close to consumption points.

3. Proposed Energy Conversion Concept

The proposed system is based on the combined utilization of three energy forms:

1. Thermal energy of hot water extracted through a heat exchanger and converted into electricity using an Organic Rankine Cycle.
2. Kinetic energy of flowing water recovered by installing micro-hydraulic turbines.
3. Low-pressure steam produced through controlled flashing of geothermal water to drive compact steam turbines.

This hybrid approach increases overall system efficiency and improves resource utilization compared to single-technology systems (DiPippo, 2016).

4. Suitable Technology

Binary cycle geothermal systems are the most appropriate option for Omani hot springs. In this configuration, geothermal fluid transfers heat to an organic working fluid with a low boiling point. The working fluid drives a turbine while the geothermal water remains in a closed loop, preventing contamination and reducing emissions (Lund & Boyd, 2016).

The modular nature of ORC systems allows small-scale and flexible installation, which is suitable for pilot projects and gradual expansion.

5. Environmental and Social Impacts

Geothermal power plants based on binary cycle technology release almost no greenhouse gases and

require limited land compared to other renewable technologies (DiPippo, 2016). Reinjection of geothermal water helps maintain reservoir pressure and preserves the natural characteristics of hot spring sites.

From a social perspective, small geothermal projects can support rural electrification, create local employment opportunities, and enhance infrastructure development. However, careful planning is required to protect tourism activities and recreational uses associated with hot springs.

6. Economic Feasibility

The economic performance of hot spring-based power generation is influenced by plant capacity, system efficiency, and capital investment. Although the initial installation cost of geothermal systems can be relatively high, operating and maintenance costs are low because no fuel is required (Ellabban et al., 2014).

Small modular plants are particularly attractive for Oman because they reduce financial risk and allow gradual scaling. Integration with local tourism and community services can further improve the overall economic value of these projects.

7. Implementation Strategy

A phased development plan is recommended:

- Site assessment and resource evaluation, including geological and hydrogeological studies.
- Pilot project installation to evaluate technical performance and operational stability.
- Environmental and regulatory approval, supported by public consultation.
- Grid connection or microgrid integration for local power supply.
- Replication and scaling at other suitable hot spring sites.

This approach allows technical learning, reduces uncertainty, and improves investor confidence.

8. Risks and Limitations

The main limitations of hot spring geothermal power generation are the relatively low fluid temperatures and possible variations in flow rate. Mineral scaling and corrosion can also affect system performance. These risks can be mitigated through appropriate material selection, regular maintenance, continuous monitoring, and reinjection strategies (Lund & Boyd, 2016).

9. Contribution to Sustainable Development

Hot spring geothermal projects support clean energy access, reduce carbon emissions, and enhance national energy diversification. They also improve electricity availability in remote areas and contribute to sustainable community development (IRENA, 2020).

10. Conclusion

This condensed study confirms that hot springs in Oman can be effectively utilized for electricity generation using low-temperature geothermal technologies. A hybrid system combining thermal, kinetic, and steam energy recovery provides an efficient and environmentally responsible solution. With proper planning, regulatory support, and pilot implementation, hot spring-based geothermal power can become an important complementary component of Oman's renewable energy portfolio.