



Greenhouse Heating Using Geothermal Brine: A Case Study from Dieng

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Abstract. This paper evaluates the feasibility of using geothermal brine from the Dieng Geothermal Field for greenhouse heating in highland potato cultivation. A thermodynamic simulation was conducted to determine the required heat load, fluid flow rates, and heat exchanger specifications for a 70 m² greenhouse. Results show that a brine flow of 0.073 kg/s and a secondary water flow of 0.056 kg/s are adequate to maintain indoor temperatures between 18–21°C. The system requires only 0.26 m² of heat exchanger surface area, making it compact and suitable for modular applications. Utilizing low-grade geothermal heat increases the plant's thermal efficiency and reduces reliance on fossil fuels. Agronomic benefits include improved tuber quality and an estimated 15–25% increase in yield during colder seasons. Environmental advantages include reduced emissions and more efficient energy use. Potential challenges, such as silica scaling and capital cost, are identified, along with suggested mitigation strategies. The study presents a sustainable approach for integrating geothermal energy into protected agriculture, particularly in highland areas.

Keywords: *Geothermal Brine, Greenhouse Heating, Highland Agriculture, Dieng Geothermal Field, Direct Use Applications.*

1. Introduction

Geothermal energy is a renewable, stable, and environmentally friendly energy source with long-term availability. Beyond electricity generation, it offers considerable potential for direct-use applications, particularly in low- to medium-enthalpy systems. According to the Lindal Diagram, geothermal fluids with temperatures ranging from 70°C to 150°C are ideal for uses such as agricultural drying, space heating, aquaculture, and greenhouse heating (Lund & Freeston, 2001). Compared to electricity generation, direct-use systems are thermally more efficient as they eliminate energy conversion and distribution losses (Curtis et al., 2005).

The Dieng Geothermal Power Plant (PLTP Dieng), operated by PT Geo Dipa Energi, is an active geothermal site in Central Java, Indonesia, utilizing a single-flash system.

In this process, geothermal fluid is separated into steam and brine; steam is used for power generation, while the brine—still retaining significant thermal energy—is reinjected without further utilization. Previous studies have reported brine reinjection temperatures between 150°C and 170°C, indicating strong potential for secondary thermal applications (Wahyudityo et al., 2013).

The Dieng Plateau, situated at approximately 2,000 meters above sea level, is a key highland agricultural region renowned for potato (*Solanum tuberosum* L.) cultivation. Potatoes thrive in daytime temperatures of 15–21°C, but night temperatures in Dieng often fall below 10°C. This thermal stress can impair photosynthesis, slow tuber formation, and increase vulnerability to diseases (Sukmawati, 2016). Greenhouse systems can stabilize microclimates, but they require auxiliary heating to maintain optimal growing conditions.

Utilizing geothermal brine as a heat source for greenhouses presents a promising synergy between renewable energy and sustainable agriculture. This integration enhances geothermal plant efficiency through cascading energy use, reduces fossil fuel dependency, and contributes to emission reduction goals (Lund, 2010). Several global case studies have demonstrated the technical and economic viability of geothermal-heated greenhouses, along with significant agricultural benefits (Dickson & Fanelli, 2004).

This study explores the feasibility of utilizing brine from PLTP Dieng to meet the thermal requirements of greenhouses for potato cultivation. Through thermodynamic analysis and system simulation, the study evaluates energy demand, brine and secondary fluid flow rates, and the required heat exchanger configuration. The findings support the development of decentralized, low-carbon heating solutions for highland agriculture in Indonesia.

This paper is structured as follows: Section 2 reviews the fundamentals of geothermal energy and its direct-use potential, with a focus on brine utilization for greenhouse heating. Section 3 describes the methodology, including data assumptions, thermal calculations, and system design. Section 4 presents the results of the thermodynamic simulation and discusses its implications for agricultural productivity and environmental impact. Finally, Section 5 summarizes the conclusions and outlines recommendations for future implementation.

2. Geothermal Energy and Agricultural Applications

2.1 Geothermal Energy

Geothermal energy originates from the Earth's internal heat, generated by radioactive decay and residual thermal energy from planetary formation. It is a sustainable, low-emission, and reliable energy source with long-term availability. Globally, geothermal energy is utilized primarily in two forms: electricity generation and direct-use applications.

The Lindal Diagram serves as a fundamental reference for determining suitable applications of geothermal fluids based on their temperature. High-enthalpy fluids ($>150^{\circ}\text{C}$) are commonly used for power generation, while fluids within the 70°C – 150°C range are ideal for direct-use applications such as agricultural drying, aquaculture, district heating, and greenhouse heating (Lund & Freeston, 2001).

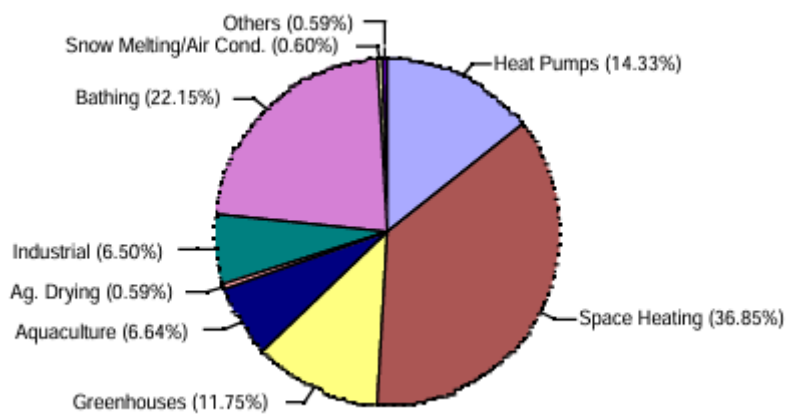


Figure 1. Global distribution of direct geothermal energy use by application sector. (Lund et al., 2011)

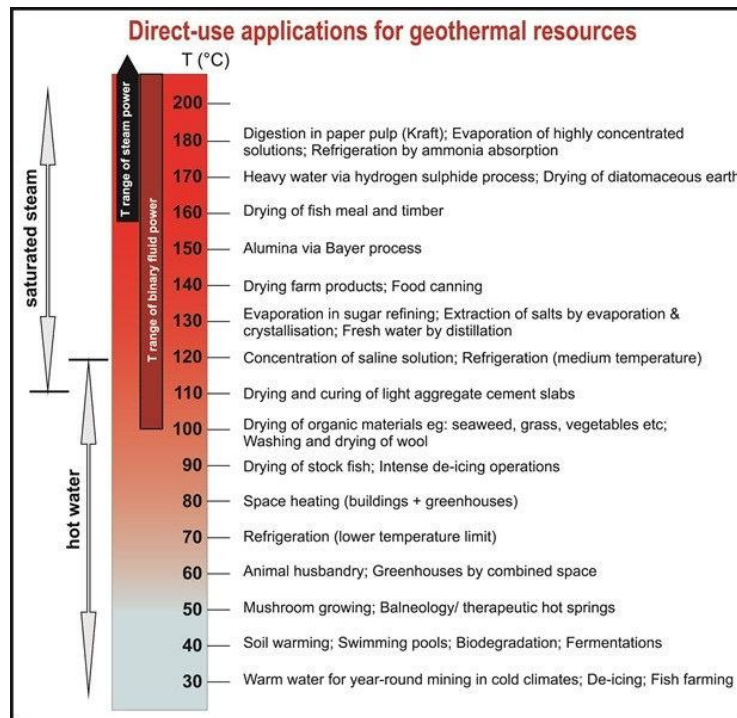


Figure 2. Temperature range of geothermal applications based on fluid enthalpy (Lindal Diagram; adapted from Lund & Freeston, 2001)

2.2 Direct Use

Direct utilization of geothermal energy has been successfully implemented in various countries including Iceland, New Zealand, and Turkey. For greenhouse heating, geothermal fluids in the range of 60°C to 120°C are typically transferred via heat exchangers or direct piping to maintain optimal internal temperatures (Lund, 2010).

Compared to fossil fuel systems, geothermal heating offers several advantages: lower operational costs, reduced greenhouse gas emissions, and extended crop production seasons. Stable thermal conditions in greenhouses are also crucial for optimizing photosynthesis and improving yield quality in horticultural systems (FAO, 2012).

2.3 Brine Utilization Potential at PLTP Dieng

The Dieng Geothermal Power Plant (PLTP Dieng) in Central Java, Indonesia, uses a single-flash separation process to extract energy from geothermal fluids. In this

system, steam is utilized for electricity generation while the remaining liquid fraction—geothermal brine—is typically reinjected into the reservoir. However, the brine still retains considerable thermal energy.

Studies have reported that reinjection temperatures at PLTP Dieng range from 150°C to 170°C (Wahyudityo et al., 2013), indicating potential for thermal reuse. Harnessing this residual heat for greenhouse heating represents an opportunity to implement cascading energy use, thereby improving overall thermal efficiency and reducing waste heat. Prior research has highlighted the economic and environmental benefits of such integration (Pambudi et al., 2015).

2.4 Potential Utilization of Geothermal Brine for Potato Cultivation

Potato (*Solanum tuberosum* L.) is a temperature-sensitive crop that requires specific thermal conditions to ensure optimal growth. Ideal daytime temperatures range between 18°C and 22°C, while nighttime temperatures should remain above 10°C (Sukmawati, 2016). In highland regions like the Dieng Plateau, nighttime temperatures often fall below this threshold, causing thermal stress that adversely affects photosynthesis, tuber formation, and overall plant vitality.

Greenhouse cultivation provides protection from temperature extremes, but during colder periods, an auxiliary heating system is necessary to maintain a stable microclimate. Utilizing geothermal brine as a heat source is particularly suitable in this context due to its stable temperature and local availability. This approach offers a sustainable and economically viable method to enhance agricultural productivity in highland areas while supporting geothermal plant efficiency through cascading utilization.

3. Methodology

3.1 Study Area and Data Collection

This study is based on the Dieng geothermal field located in Central Java, Indonesia, at an elevation of approximately 2,000 meters above sea level. The geothermal power plant utilizes a single-flash system, with brine discharge temperatures typically ranging from 150°C to 170°C. Technical data were obtained from existing literature, including Wahyudityo et al. (2013) and Pambudi et al. (2015). Potato thermal requirements were referenced from FAO (2012) and Sukmawati (2016), while thermal properties and heat transfer values were adopted from Cengel & Boles (2015).

3.2 Assumptions and Parameters

To simulate system performance, the following assumptions and references were used:

- Greenhouse area: 70 m² (7 × 10 m) (Author assumption)
- Heating requirement: 100 W/m², based on greenhouse needs in cold highland environments (FAO, 2012).
- Brine inlet/outlet temperatures: 180°C and 150°C, consistent with temperature ranges reported at PLTP Dieng (Wahyudityo et al., 2013).
- Heating fluid temperature (in/out): 40°C to 70°C, suitable for greenhouse climate control (FAO, 2012).
- Heat exchange efficiency: Assumed at 80%, as commonly reported for compact geothermal heat exchangers (Pambudi et al., 2015).
- Specific heat capacities: 4.18 kJ/kg°C for water, and 4.00 kJ/kg°C for brine (Cengel & Boles, 2015).
- Heat transfer coefficient (U): 250 W/m²·K, representing clean stainless-steel heat exchanger surfaces (Cengel & Boles, 2015).

3.3 Thermal Analysis

The total heat demand Q for a 70 m² greenhouse is calculated as:

- $Q = A \times q = 70 \text{ m}^2 \times 100 \text{ W/m}^2 = 7000 \text{ W}$

Where:

- A = greenhouse area
- q = heating demand per unit area

3.4 Mass Flow Rate Calculations

For secondary heating water:

- $Q = \dot{m}_{\text{water}} \times C_p \times \Delta T = \frac{Q}{C_p \Delta T} = \frac{7000}{4.18 \times (70-40)} = 0.056 \text{ kg/s}$

For geothermal brine:

- $\dot{m}_{\text{brine}} = \frac{Q}{C_p \Delta T} = \frac{7000}{4.00 \times (180-150)} = 0.073 \text{ kg/s}$

3.5 Heat Exchanger Surface Area

The heat exchanger surface area A is estimated using the Log Mean Temperature Difference (LMTD) method:

$$A = \frac{Q}{U \Delta T_{lm}}$$

Where:

- $U = 250 \text{ W/m}^2 \cdot \text{K}$
- $\Delta T_1 = 180 - 70 = 110^\circ\text{C}$; $\Delta T_2 = 150 - 40 = 110^\circ\text{C}$
- $\Delta T_{lm} = \frac{110-110}{\ln\left(\frac{110}{110}\right)} \approx 110^\circ\text{C}$
- $A = \frac{7000}{250 \times 110} = 0.2545 \text{ m}^2 \approx 0.26 \text{ m}^2$

3.6 System Configuration

The heating system consists of three main components:

- Insulated brine pipeline from the separator to the heat exchanger.
- Shell-and-tube heat exchanger, where heat is transferred from geothermal brine to the heating fluid.
- Closed-loop water distribution network inside the greenhouse.
- Temperature sensors and control valves to regulate the flow and maintain indoor temperatures between 18°C and 21°C .

4. Result

The thermodynamic simulation shows that a geothermal brine flow rate of 0.073 kg/s is sufficient to supply the heating demand of a 70 m^2 greenhouse, with a required thermal load of $7,000 \text{ W}$ (or 100 W/m^2). This heating capacity is designed to mitigate nighttime temperature drops and minimize heat loss through the greenhouse envelope—conditions that are common in the Dieng Plateau and pose challenges to potato cultivation.

To deliver this heat, a secondary water loop with a flow rate of 0.056 kg/s , heated from 40°C to 70°C , is circulated in a closed-loop system inside the greenhouse. These flow rates are modest and can be managed using commercially available equipment, making the system suitable for decentralized and modular applications. The geothermal brine required represents only a small portion of the available reinjection flow at PLTP Dieng, suggesting the feasibility of expanding this system to multiple greenhouses without compromising reinjection operations.

The heat exchanger surface area, calculated using the Log Mean Temperature Difference (LMTD) method, is approximately 0.26 m^2 . This compact configuration allows for simple integration, cost efficiency, and ease of installation—particularly beneficial for smallholder farming operations.

4.1 AGRONOMIC IMPLICATIONS

The simulation confirms that the proposed heating system can maintain greenhouse temperatures between 18°C and 21°C, aligning with the optimal thermal range for potato (*Solanum tuberosum* L.) vegetative growth and tuber formation (Sukmawati, 2016). In highland regions such as Dieng, where nighttime temperatures often drop below 10°C, this stability is crucial for avoiding physiological stress that can lead to delayed maturation, reduced tuber size, and lower yields. By maintaining ideal thermal conditions, the geothermal-based system is projected to improve crop productivity by 15–25% during colder growing seasons, in line with prior agronomic findings.

4.2 ENVIRONMENTAL AND ENERGY EFFICIENCY BENEFITS

From an environmental perspective, this system exemplifies cascading energy use, where geothermal brine—typically reinjected without utilization—is repurposed for direct-use applications. This increases the overall thermal efficiency of the power plant and reduces reliance on fossil fuels for greenhouse heating, supporting national objectives related to low-carbon agriculture and renewable energy integration. Furthermore, localized direct-use systems such as this reduce greenhouse gas emissions, while enabling year-round agricultural productivity in mountainous rural regions.

4.3 TECHNICAL AND OPERATIONAL CHALLENGES

While technically feasible, several challenges must be addressed for successful field implementation:

- Silica scaling in heat exchangers can reduce thermal efficiency and damage system components over time. This risk can be mitigated through brine pretreatment, chemical anti-scaling injection, and periodic cleaning.
- Initial capital investment, although moderate, requires techno-economic assessment to ensure affordability and cost-effectiveness, especially for individual farmers or agricultural cooperatives.
- Operational integration will depend on effective collaboration among geothermal operators, local farmers, and agricultural extension services to ensure proper system installation, training, and maintenance.

5. Conclusion

This study confirms the technical feasibility of utilizing geothermal brine from the Dieng Geothermal Field as a heat source for greenhouse applications, specifically for highland potato cultivation. Through thermodynamic analysis, it is demonstrated that a brine flow rate of 0.073 kg/s and a secondary water flow of 0.056 kg/s are

sufficient to meet the heating demand of a 70 m² greenhouse, maintaining internal temperatures within the optimal range of 18°C to 21°C.

The system requires only 0.26 m² of heat exchanger surface area, indicating a compact and modular design suitable for decentralized agricultural applications. In addition to agronomic benefits such as 15–25% yield improvement, the proposed system offers environmental advantages by increasing the thermal efficiency of the geothermal plant and reducing reliance on fossil fuels.

To advance the implementation of geothermal direct-use systems in agriculture, the following steps are recommended:

1. Pilot-scale field testing to validate simulation results under real operating conditions.
2. Techno-economic analysis to assess cost-effectiveness and investment feasibility for different greenhouse scales.
3. Stakeholder collaboration between geothermal operators, farmers, and policymakers to support deployment, maintenance, and adoption.

Overall, the findings from this study contribute to the development of sustainable, low-carbon agricultural systems in highland regions and demonstrate the untapped potential of geothermal brine as a clean energy resource for food security and rural development.

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