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# Sustainability of geothermal power plant combined with thermodynamic and silica scaling model

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ABSTRACT

This method of combining thermodynamic and silica scaling analysis aims to improve efficiency, power output and sustainability in geothermal power plants which suffer from high concentration of silica. The proposed method was employed in an analysis of the Dieng geothermal power plant. The process starts with a performance evaluation of the existing power plant system, which is comprised of many components where losses of both energy and exergy occur. Once the performance of the existing plant has been evaluated, optimization of operating parameters can be applied to maximize its power output without the expensive addition of any new components. The process then continues with the development of scenarios with the power plant's design, seeking potential methods to improve its performance. In these scenarios, the plant is expanded into a double flash system, single flash-binary and double flash-binary. Silica scaling behavior models are then applied to determine which is the best scenario for development.

It was found that a double flash system is the best expansion scenario for Dieng Geothermal Power Plant. This scenario produces a high power output of 29,155 kW and the lowest excess deposit of silica at 899 ppm. Although this scenario produces lower power output than the double flash-binary system, it has less negative impact from silica scaling. By introducing this system, the company can obtain additional power output of 4855 kW.

Cp Specific heat (kJ/kgK)
Exergy rate (kW)
Specific exergy (kJ/kg)
Mass flow rate (kg/s)
S Specific entropy at stream i (kJ/kg-K)
H Specific enthalpy (kJ/kg)
T Temperature (K)
η Efficiency (−)
X Dryness fraction
Work (kW)
EES Engineering equation solver
LPS Low pressures separator
HPS High pressure separator
LPT Low pressure turbine
HPT High pressure turbine
GHG Greenhouse gas
NCG Non-condensable gas
TFT Tracer flow test
B Brine
ct Cooling tower
hps High pressure separator
i Stream i
0 Reference state
out Output
in Input
II Second law
t Turbine
th Thermal
e Electricity

## 1. Introduction

Over the last few decades, global primary energy consumption has increased significantly due to population growth and economic development, including higher living standards and the evolution of technology (Morikawa, 2012; Begum et al., 2015; Chun-sheng et al., 2012). Energy consumption is mainly supplied by fossil fuels that produce negative impacts such as greenhouse gases (GHG) which pollute the

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**Nomenclature**

*Subscript*

| | |
|---|---|
| *B* | Brine |
| *ct* | Cooling tower |
| *hps* | High pressure separator |
| *i* | Stream i |
| *0* | Reference state |
| *out* | Output |
| *in* | Input |
| *II* | Second law |
| *t* | Turbine |
| th | Thermal |
| e | Electricity |

environment (Gerbelová et al., 2013; Fuss and Szolgayová,2010). Another concern about excessive use of fossil fuels is their limited availability and eventual depletion. In the long term, renewable resources can replace fossil fuels and reduce the associated problems.

Geothermal power is renewable energy contained in deep or shallow reservoirs within the Earth. These reservoirs have come to hold deposits of hot fluid during complex geological processes over long periods of time. The water held within the rock may flow towards the surface through fissures along a pressure gradient naturally or artificially. Like many renewable energy sources, geothermal energy produces low carbon emissions. Another advantage of geothermal power is that it is a non-intermittent resource, which means that energy can be produced continuously without interruption except during the maintenance of power plants. Many countries have considerable high enthalpy geothermal resources, including Indonesia, the USA, Japan and the Philippines. However, most of the European countries utilize low enthalpy and shallow geothermal resources (Østergaard, 2011; Rosiek and Batlles, 2012; Karytsas et al., 2003).

Over the last decade, many technologies have been developed to increase energy efficiency in several sectors, including power generation, transportation, commercial uses and conversion. Increased efficiency reduces the contribution of fossil fuels to global warming, which is increasingly severe. Many researchers have analyzed the potential of improving efficiency through thermodynamic methods in geothermal power plants (Pambudi et al., 2014; Jalilinasrabady et al., 2010); methods they have explored include incorporating a double flash system (Pambudi et al., 2015a; Jalilinasrabady et al., 2012), and applying the organic Rankine cycle (Kanoglu, 2002; Makhanlall et al., 2015; Zare, 2015; Budisulistyo and Krumdieck, 2015), Kalina cycle (Li et al., 2016), interstage reheating (DiPippo, 2013), a double evaporator (Wang et al., 2017), $CO_2$ transcritical power cycle (Li and Dai, 2014) and other combination methods (Wang et al., 2015). There are additional important details to look at, namely the silica content in the fluid, which can have a severe impact on the sustainability of the power plant. Silica causes a decline in electricity production by clogging production or injection wells (Utami, 2000; Demir et al., 2014; Mundhenk et al., 2013; Gunnarsson and Arnórsson, 2005; Pambudi et al., 2015b; Baba et al., 2015). The issues arising from silica scaling provide a sharply contrasting force to the initial goal of improving efficiency. Although high silica content in geothermal fields cannot be avoided, we can modify equipment to reduce its effects. Therefore, methods to improve efficiency and reduce the impact of silica on power plants are very much necessary.

In this paper we offer a combination method of thermodynamics and silica analysis with the aim of improving the efficiency and sustainability of long-term power generation at a geothermal power plant. The Dieng geothermal power plant in Indonesia is used as an example to apply these methods. The thermodynamic method is used to evaluate the efficiencies and losses in the plant. Meanwhile, silica concentrations are compared in each development scenario. Experiments are also conducted on site to analyze silica concentration. We collect brine samples at several points and measure silica concentration, pH and temperature. This combination method has not been applied before, but it can be the solution that obtains the best scenario for geothermal power plant expansion.

## 2. Performance evaluation of existing single flash plant at dieng

The power plant at Dieng currently has a single-flash system. This type of flash system is used in all geothermal plants in Indonesia except for Darajat and Kamojang (Pambudi, 2017). The Dieng geothermal power plant, located in the southern central region of Indonesia's Java province, has been identified as one of the most significant geothermal prospects in the country. Dieng has a reservoir temperature around 310 °C. The installed capacity of 60 MW is supplied by steam from ten production wells at five locations. Because of severe problems with silica scaling at the plant, its power output has decreased drastically.

The single flash process collects a huge quantity of brine in the separator. This brine is then injected back into the reservoir through canals and the precipitation system. During this injection process, the brine releases heat while its pressure and temperature drop. Great amounts of energy and exergy are released, which is less favorable thermodynamically.

Exergy analysis and optimization of the Dieng single flash geothermal power plant has been investigated. Despite its 60 MW of installed capacity, severe silica scaling occurs has caused the actual capacity to drop from its initial capacity (Pambudi et al., 2014). Fig. 1 shows a model diagram of the Dieng single flash system. Geothermal fluid is drawn from the reservoir through the well and is separated into steam and liquid brine in the separator. In 2013, the plant was supplied with steam from ten production wells at five locations. The separator pressure is different in each wellpad since the fluid enthalpy from

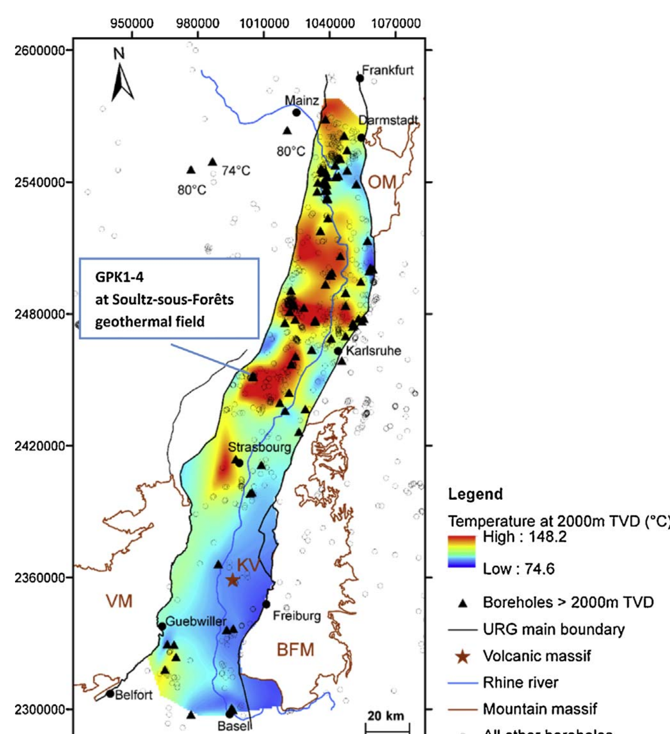


**Fig. 1.** A model diagram of single flash geothermal power plant.