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# Cryogenic energy storage powered by geothermal energy

Tugberk Hakan Cetin[a], Mehmet Kanoglu[b,*,1], Neslihan Yanikomer[a]

[a] Institute of Energy Technologies, Gebze Technical University, 41400 Kocaeli, Turkey
[b] Department of Mechanical Engineering, University of Gaziantep, 27310 Gaziantep, Turkey

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ABSTRACT

Geothermal energy is one of the promising alternatives of power generation suitable for energy storage applications for load shifting operations. Cryogenic energy storage (CES) is an attractive option for energy storage driven by geothermal power. In this study, thermodynamic assessment of a cryogenic energy storage unit integrated to a single-flash geothermal power plant is performed and the effect of geothermal source temperature on the system performance is investigated. Initially, a resource that can supply geothermal water at 180 °C at a rate of 100 kg/s is considered. Power generated from the geothermal plant during off-peak hours is used to produce and store liquefied air. This liquefied air is used to generate power during peak hours using the heat of geothermal water. Our analysis indicates that the liquefaction unit consumes 4304 kW power in order to liquefy air for a 6-h charging period. In the discharge mode, the CES unit can produce a net power output of 12,049 kW for a 1-h operation. The flashing pressure is optimized at 255 kPa for which the total power output is 16,100 kW. The round-trip efficiency of the CES unit is determined to be 46.7% while the overall efficiency of the integrated system is 24.4%.

## 1. Introduction

Geothermal energy is the form of thermal energy that is harvested from beneath of the earth surface. Power generation from geothermal energy is a mature branch of the renewable power technology and used commercially for more than a century (Aneke and Menkiti, 2016). Geothermal power plant capacity is expected to reach 21 GW in 2020 and geothermal energy will meet 8.3% of energy production in the world by 2050 (Bertani, 2016). Unlike some other renewable energy sources such as solar and wind, geothermal energy is a continuous energy source which makes it suitable for base load power generation.

For power plants operating on base load, daily demand does not always match with the plant output. During off-peak times, when power demand is lower than the plant's output, system's power output is down-regulated or completely shut down. These operations are costly and reduce the plant's life. To address this, one may consider hydrogen production by geothermal power (Kanoglu et al., 2007; Yilmaz et al., 2012). Another alternative for off-peak operation is energy storage. During off-peak hours, excess electricity is stored in a storage medium and discharged during peak hours to meet the demand.

Cryogenic energy storage (CES) is one of the promising large-scale energy storage technology. During off-peak hours, the electricity produced is used to liquefy air, and this liquefied air is stored in tanks. During peak hours, liquefied air is discharged, heated by atmospheric heat and other available heat source, and expanded in a turbine to produce electricity to match the demand of the network (Morgan et al., 2015).

Storing energy as liquid air has several advantages. Unlike other large-scale energy storage systems such as pumped-hydro or compressed air energy storage (CAES) systems, CES systems have no geographical constraints. Besides, air liquefaction systems are well-known and mature technology settled in industry and also cost competitive (Akinyele and Rayudu, 2014; Chen et al., 2009).

The first pilot scale liquid air energy storage (LAES) plant with a capacity of 350 kW/2.5 MW h was installed in 2008. The analysis and performance data of the plant were presented by Morgan et al. (2015). The pilot plant has a response time of 100 s and converts 45% of the low-grade heat to power. Khalil et al. (2017) presented a study of a micro-grid scale LAES and power generation system. Proposed system could reach up to 84% round-trip efficiency. Krawczyk et al. (2018) carried out comparative study of CAES and LAES systems and determined energy storage efficiencies of 40% and 55% for the considered systems, respectively. Also, the energy density of the LAES system was found to be six times greater than that of the CAES system. Li et al.

* Corresponding author.
*E-mail address:* kanoglu@gantep.edu.tr (M. Kanoglu).
[1] On leave at Department of Mechanical Engineering, American University of Sharjah, 26666 Sharjah, United Arab Emirates.

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**Nomenclature**

| | |
|---|---|
| $c_1$ | Mass flow rate ratio of cold recovery unit I |
| $c_2$ | Mass flow rate ratio of cold recovery unit II |
| $h$ | Specific enthalpy (kJ/kg) |
| $g$ | Mass of air liquefied per mass of geothermal water |
| $\dot{m}$ | Mass flow rate (kg/s) |
| $P$ | Pressure (kPa) |
| $q$ | Heat transfer per unit mass (kJ/kg) |
| $Q$ | Heat transfer (kJ) |
| $s$ | Specific entropy (kJ/kg-K) |
| $T$ | Temperature (K, °C) |
| $t$ | Operation time (h) |
| $R$ | Gas Constant (kJ/kg-K) |
| $W$ | Specific work (kJ/kg) |
| $\dot{W}$ | Power (kW) |
| $y$ | Liquid yield ($\dot{m}_f/\dot{m}$) |

*Greek Letter*

| | |
|---|---|
| $\eta$ | Efficiency |
| $\Delta$ | Difference |

*Subscripts, indices*

| | |
|---|---|
| 1,2,3.. | States of the cycle |
| c | Cold recovery |
| ces | Cryogenic energy storage |
| comp | Compressor |
| geo | Geothermal |
| liq | Liquefaction |
| th | Thermal |
| turb | Turbine |
| rt | Round-trip |

(2014) proposed a CES integrated nuclear power plant for load shifting applications. Proposed system has a round trip efficiency of around 70%. Antonelli et al. (2017) investigated potential hybrid power plants integrated with LAES systems with and without combustion. Li et al. (2010) compared liquid hydrogen and liquid air/nitrogen as energy carriers. Liquid air was found as more cost competitive than liquid hydrogen mainly due to its lower capital cost.

In this paper, we propose a cryogenic energy storage system integrated with a single-flash geothermal power plant. According to Bertani (2016), about a third of geothermal power plants operate on single-flash cycle. The studies on cryogenic energy storage systems have considered a conventional fossil-fuel based power plant, a nuclear plant, or a renewable power unit such as solar or wind to drive a CES unit. A survey on the open literature shows that this is the first study considering a geothermal power plant for driving a cryogenic storage system.

This paper presents thermodynamic assessment of CES unit integrated to a single-flash geothermal power plant. For this purpose, a geothermal resource at 180 °C supplying geothermal water at a rate of 100 kg/s is considered. The overall and the round-trip efficiency of the proposed system are evaluated. Effect of geothermal resource temperature and the outlet pressure of the CES unit are investigated.

Geothermal power plants present unique opportunities for cryogenic energy storage. In a single-flash geothermal power plant, the geothermal liquid water is separated from the vapor after the flashing process and this liquid water is reinjected back to the ground at a

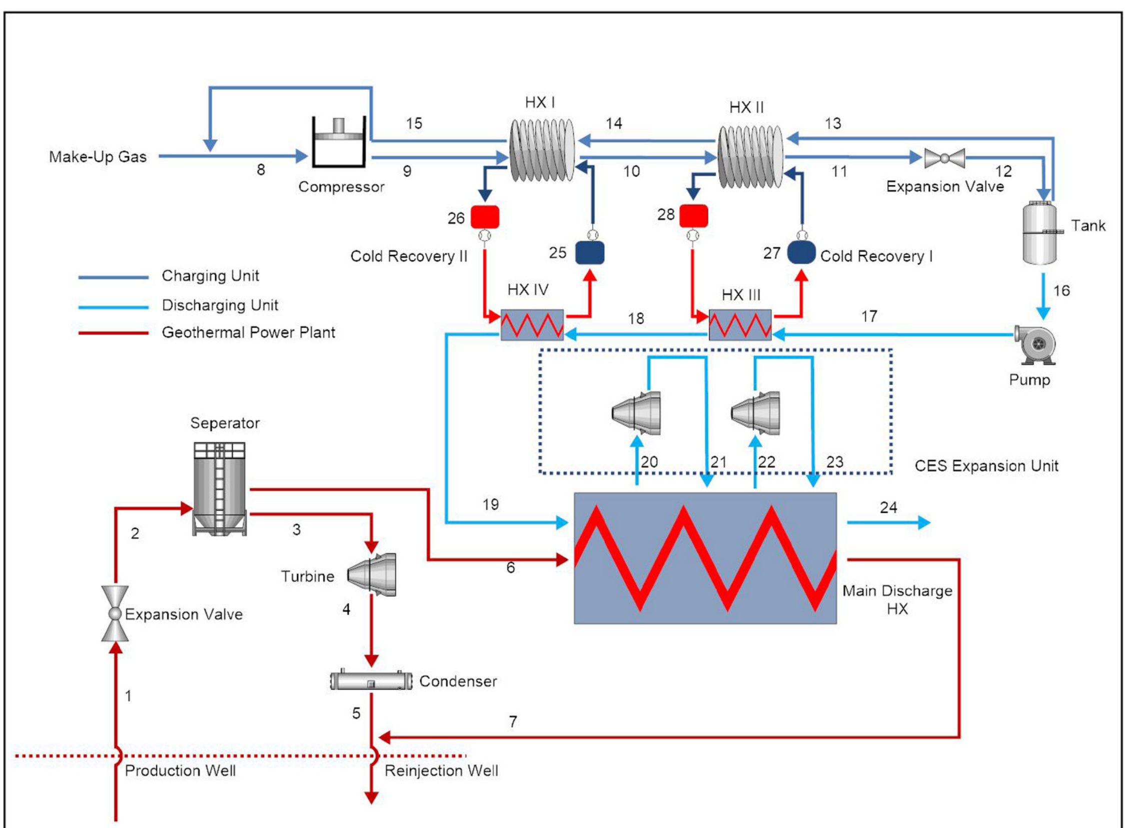


**Fig. 1.** Schematic representation of CES integrated single flash geothermal power plant.