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Pumped heat energy storage with liquid media: Thermodynamic assessment by a transcritical Rankine-like model

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ABSTRACT

A pumped heat energy storage (PHES) system based on a Rankine cycle for supercritical working fluids, such as carbon dioxide and ammonia, accounting for the irreversible latent and sensible heat transfers between the working fluid and the storage liquid medium, as water or thermal oil, is analyzed. The model also includes several parameters such as pressure losses, heat exchanger efficiencies, and isentropic efficiencies of the compressor, pump, and expansion devices (such as turbines and valves), that take into account the main internal and external losses and heat leak to the environment. The model allows for the calculation of specific energy, the heat pump performance coefficient, heat engine efficiency, and overall round-trip efficiency, as well as the temperatures of the working fluid and reservoirs. A zero-dimensional model is also used to determine the time dependence of heat leak in the tanks. The main results show that this technology could achieve round trip efficiency values in the order of 50–70%. Irreversibilities in compression and expansion appears as the most influential energy losses factor. The time effect of the ambient conditions on the tanks has been analyzed for a wet subtropical climate but it seems that the ambient conditions have no major influence on the performance of the system. In addition, explicit numerical results and temperature–entropy plots are presented for two representative systems as carbon dioxide-water and ammonia-thermal oil to take into account the main values in an operating condition.

1. Introduction

To reduce emissions of CO_2, and surpass the increase in fuel prices and the more restrictive environmental regulations, the control of energy consumption becomes more and more important [1]. Along this line, it is essential to reduce the use of fossil fuels through electricity generation systems from renewable sources (wind, hydroelectric, photovoltaic, etc.). However, beyond the economic and environmental advantages, the production of electricity from renewable sources can be intermittent and difficult to control by the electric grid operators. In addition, it is important to point out that the energy consumption of the communities is usually quite regular, with high demand at certain times of the day which, in general, are non-coincident with the peaks in the renewable energy production [2].

According to the need to avoid these variations, without the use the fossil fuel power plants, it is appealing that the analysis of novel energy storage systems could improve the grid stability, increase the penetration of renewable energy resources, conserve fossil energy resources, and reduce the environmental impact of power generation. One kind of useful technology to achieve the above goals is based on the store of surplus electricity in the form of high temperature heat and power [3] employing a heat pump device (charge period) from where it is then extracted (discharge period) as electrical energy using a thermal heat engine when needed [4]. This technology can be used not only for electricity storage/production but also for cogeneration of electricity and heat or even trigeneration of electricity, heat, and cold. In [5], a detailed description and fundamentals of the system and how it works are presented. Currently, there have been few experiences in thermal storage. In 2014 in Germany, a small-scale pilot plant was installed in Hamburg Bergedorf [6] with a storage capacity of 5 MWh where various storage concepts, materials, and assemblies were tested. Then, it was upgraded to a capacity of 130 MWh stored in volcanic rocks that were connected to the Hamburg grid in June 2019. Also,

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