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Research Paper

The influence of magnetic field on heat transfer of magnetic nanofluid in a double pipe heat exchanger proposed in a small-scale CAES system

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HIGHLIGHTS

- A double pipe heat exchanger before cavern is proposed for a CAES system.
- Fe_3O_4/water nanofluid is considered as the secondary fluid for the proposed heat exchanger.
- The influence of magnetic field on heat transfer of Fe_3O_4/water nanofluid is investigated.
- Increasing the mass flow rate of secondary fluid decreases the cavern temperature.
- Increasing the volume fraction and magnetic field increases the pressure drop and friction factor of ferrofluid.

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ABSTRACT

Globally, the integration of renewable energy (which has an intermittent nature) into the power system requires the system operators to improve the system performance to be able to effectively handle the variations of the power production in order to balance the supply and demand. This problem is seen as a major obstacle to the expansion of renewable energy if it is not handled in a suitable way. Efficient electricity storage technology is one of the feasible solutions. The current study proposes Fe_3O_4/water nanofluid under magnetic field as the secondary fluid in the proposed double pipe heat exchanger before the cavern. The heat of compressed air is absorbed by the secondary fluid and it is stored in an isolation tank. This stored fluid is used to warm up the air that leaves the cavern for expanding in the turbine. The results demonstrated that increasing the mass flow rate of secondary fluid decreases the cavern temperature. Also, the value of convective heat transfer of ferrofluid increases when the volume fraction of nanoparticle as well as magnetic field increases. Furthermore, increasing the volume fraction and magnetic field increases the pressure drop and friction factor of ferrofluid.

1. Introduction

Renewable energy sources (such as solar, wind, ocean thermal, and geothermal) are extensively available and have a potential to meet the energy demand of the whole mankind [1,2]. However, harnessing of these renewable energy sources for energy production units is not a simple process, due to several reasons including intermittency, changing weather condition, time, and geographical location. One solution to this problem is to introduce energy storage systems such as compressed air energy storage (CAES), hydrogen storage system, and battery [3]. CAES is an alternative to pumped hydro, since it has relatively high power output and storage capacity. Instead of pumping water to an upper reservoir when the electricity supply is high, atmospheric air is compressed and stored in underground facilities under high pressure in CAES system [4]. When the demand for electricity is high, the stored air is heated and expanded through a generator to produce electricity [5].

There are currently two CAES plants in operation worldwide. The first one was installed in Huntorf, Germany in 1978 and the second one, located in McIntosch-USA, was put into operation in 1991. Both systems compress air adiabatically and use the natural gas as heat sources for discharge process. Many investigations have been developed recently to improve CAES system [6,7]. Szablowski et al. [8] constructed a dynamic mathematical model of an adiabatic CAES system using Aspen Hysys software. The volume of cavern for the studied CAES system was considered as 310,000 m^3. Also, the operation pressure

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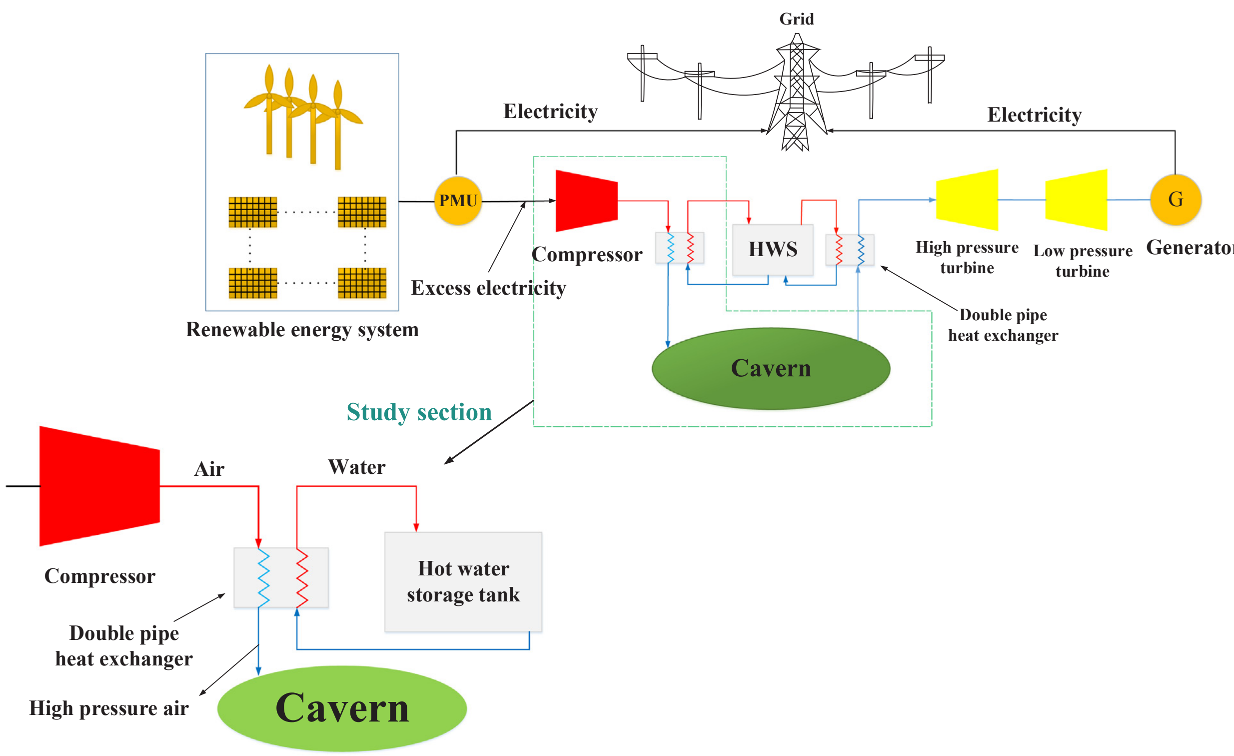

Fig. 1. Schematic diagram of the proposed system.

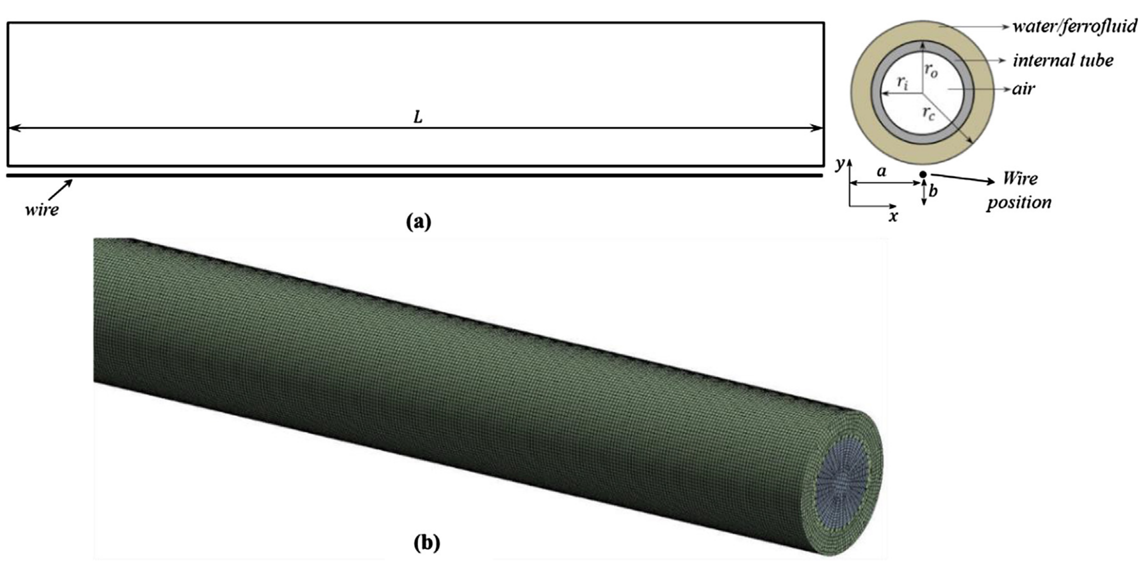

Fig. 2. (a) Geometry of the problem, with = 3 m, r_i = 5.35 mm, r_o = 6.35 mm, r_c = a = 8.525 mm, b = 1 mm, and (b) cell discretization schematic.

Table 1
Thermo-physical properties of materials.

Material	ρ (kg/m^3)	C_p (J/kg·K)	k (W/m·K)	μ (kg/m·s)
Air	1.225	1006.43	0.0242	0.000018
Water (base fluid)	998.2	4182	0.6	0.00103
Fe_3O_4 (particle)	5200	670	6	–
Ferrofluid with 2 vol%	1081.84	4109.36	0.63591	0.001082
Ferrofluid with 4 vol%	1165.47	4036.72	0.67328	0.001133

inside the cavern changed from 43 to 70 bar. Their results demonstrated that the maximum exergy destruction was occurred in the compressor and turbine. Wang and Bauer [9] analyzed the pressure response of large-scale CAES system in porous formations. The developed model showed that the induced pressure changed laterally throughout the storage formation was due to initial filling of the air storage. Houssainy et al. [10] implemented a thermodynamic analysis of a high-temperature hybrid CAES system. They have showed the importance of thermal storage temperature and pressure on the system. An optimum operating pressure was proposed in order to obtain the maximum roundtrip storage efficiency of the proposed hybrid storage system.

For an adiabatic CAES system, a novel throttling strategy (by considering an internal ejector) was proposed by Chen et al. [11]. For this new system, the internal ejector increases the inlet pressure of high-pressure turbine that can lead to increasing in the system efficiency. In addition, their results have demonstrated that employing the internal ejector can increase the roundtrip efficiency approximately by 2%. An accurate prediction of the energy storage capacity of a cavern with a