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Experimental and theoretical investigation of thermal performance of underground cold-water reservoirs

A.A. Dehghan [a,*], A.R. Dehghani [b]

[a] School of Mechanical Engineering, Yazd University, P.O. Box 89195-741, Yazd, Iran
[b] Department of Mechanical Engineering, Islamic Azad University, Science & Research Campus, Tehran, Iran

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ABSTRACT

Thermal performance of a traditional, underground cold-water reservoir (cistern) is investigated both experimentally and analytically. An innovative analytical solution technique for determination of the temperature distribution in the reservoirs is developed by employing a linearized boundary condition at the water surface. The theoretical predictions are then compared with the extensive experimental measurements obtained in a traditional underground cold-water reservoir located in the city of Yazd in central region of Iran. Good agreement between the analytical and the experimental results demonstrates the validity of the proposed analytical solution method. Both the experimental data and analytical results show that a stable thermal stratification develops within the water reservoir and is preserved throughout the entire course of water withdrawal cycle. Both results demonstrate that while the outside ambient temperature reaches 42 °C during the summer time, cool drinking water with the temperature ranging from 12 to 13 °C is readily available from the water withdrawal tap of the reservoir. Parametric studies show that decreasing induced wind velocity over the water surface or increasing the ambient temperature leads to an increase in the top water layer temperature, while the bottom water layers are not significantly affected. This finding is important as it confirms that the traditional cold storage reservoirs are capable of protecting the bottom cold-water layers from harsh outdoor environment. Further, it is observed that for these water reservoirs and for selected storage aspect ratios beyond one, bottom layers temperatures are not influenced by the variation of the reservoir aspect ratio. Utilizing the experimental results, an energy and exergy analysis shows that around 80% of the cooling capacity stored in the winter can be retrieved during the summer time at a desired temperature. Comparing the exergy content of the stratified reservoir with that of the fully mixed tank shows that the formation of stable thermal stratification is responsible for preserving the quality of the extracted cold energy.

1. Introduction

Passive cooling systems were common in hot, arid regions of developing countries in order to provide cool air or cold drinking water during the hot summer season. Cold Thermal Energy Storage (CTES) Systems may work on a diurnal or seasonal basis. The first type stores cold energy during the night and delivers it during the daytime when the demand for cooling load is high. Long-term CTES systems are among passive cooling systems which work on a seasonal basis and take advantage of seasonal climate variation in order to store cold energy during winter and retrieve it during summer time. A comprehensive review of the studies on the concept of CTES, their applications, variety and merits has been conducted by Dincer and Rosen [1] and Saito [2].

Thermal stratification is frequently utilized in the thermal storage systems. Therefore, the main focus of the relevant studies has been on the influence of various design parameters on preserving the thermal stratification. Nelson et al. [3] experimentally investigated the effects of storage tank dimensions, its wall physical properties and the mixing effects of fluid flow during charging and discharging cycles on the decay of thermal stratification in a thermally stratified, cylindrical chilled-water storage tank. Their results showed that increasing the height to diameter ratio of the tank prevents the degradation of thermal stratification; however, the effects for the aspect ratios greater than three were marginal. Bahadori and Haghighat [4] numerically investigated the thermal characteristic of a long-term cold-water storage cistern in hot, arid regions by the finite difference method, assuming a simplified thermal boundary condition at the water surface. They showed that a stable thermal stratification develops in the cistern with the temperature of the upper layers being approximately a function of the surrounding air temperature and the

* Corresponding author. Tel.: +98 351 8122493; fax: +98 351 8210699.
E-mail address: adehghan@yazduni.ac.ir (A.A. Dehghan).

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