

Experimental setup for tank stratification in the liquid air storage tank in the liquid air energy storage integrated to PWR steam cycle

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1. Introduction

The electric grid has become more reliant on load-following capability as the percentage of renewable energy grows. The need for more energy storage, as well as the need for conventional power to reduce their load during periods of excess supply, is increasing as a result of the intermittency introduced by renewable sources.

The concept of incorporating large-scale energy storage systems (ESS) has been discussed to regain cost-competitiveness for traditional energy sources such as nuclear power during overproduction [1-4]. By combining a large-scale ESS with a traditional nuclear plant, it would be able to store electricity during off-peak hours and discharge it when it is most needed, generating additional revenue by price arbitrage.

Liquid air energy storage (LAES) has recently received recognition as one of the promising large-scale ESS developments [5]. LAES has a greater energy density and is not limited by geological limitations as compared to compressed air energy storage or pumped hydro storage [6]. Li et al. (2014) suggested combining LAES with a 250MWe light-water reactor [7]. An LAES integration layout for a reference pressurized water reactor (PWR) was also suggested by the KAIST research team, as shown in Fig. 1 [8].

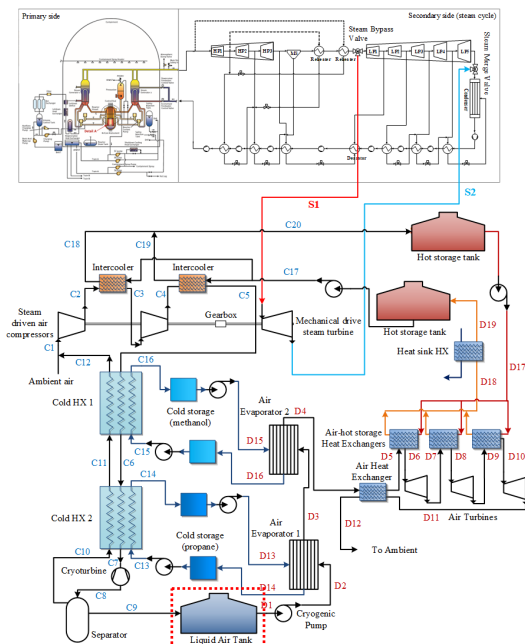


Fig. 1. Schematic of LAES integrated to PWR steam cycle [8]

The storage of energy in cylindrical tanks of liquid air, a mixture of mostly nitrogen, oxygen, and argon, is known as liquid air energy storage. Nevertheless, the components of air as a mixture are known to have variable densities and boiling points, as seen in Table 1. During the charging cycle, the storage tank is filled with evenly mixed liquid air. Since the idle time between charging and discharging modes can range from hours to days, the mixture can stratify due to variations in density and temperature.

The stratification due to temperature and concentration can lead to two issues: 1) safety concern for rollover leading to over-pressurization and 2) performance degradation due to off-design operation. These issues become critical especially when LAES is integrated to large-scale nuclear plants. Though stratification issue is important, the conditions under which it may occur have not been fully investigated.

The purpose of this paper is to describe the experimental setup for investigating the tank stratification in the liquid air storage tank over time.

2. Experimental setup for LAES tank stratification

The experiment setup requires the data collection of independent and dependent variables to investigate the conditions under which tank stratification occurs. As shown in Fig. 2, the temperature and O₂ concentration profile need to be obtained in the z-direction, with the independent variables of heat ingress, level fraction, and maximum tank pressure. These values are altered to provide a set of conditions under which the liquid air is stored.

The actual experimental setup is shown in Fig. 3, with the labeled equipment. The heat ingress is altered by using an integrated vacuum control system consisting of a vacuum pump, a vacuum gauge, and a controller. The degree of vacuum in the tank vacuum insulation is varied from 10^{-4} ~ 10^{-2} torr. Furthermore, the level fraction is measured indirectly using a weight scale by estimating the height of the filled liquid air through the added mass of the tank system.

The measurement of temperature is done using a set of 40 T-type thermocouples (TC) aligned together on a machined SS304 bar, as shown in Fig. 4. The data collection of the boil-off gas mass flow rate is conducted using a gas mass flow meter (MFM). All the sensors are connected to the NI DAQ system through which the data is then sent to the PC to be acquired by LabVIEW.

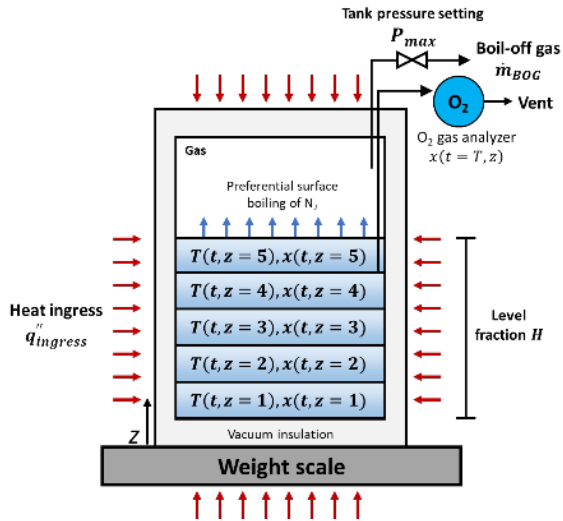


Fig. 2. Schematic of tank stratification experiment parameters

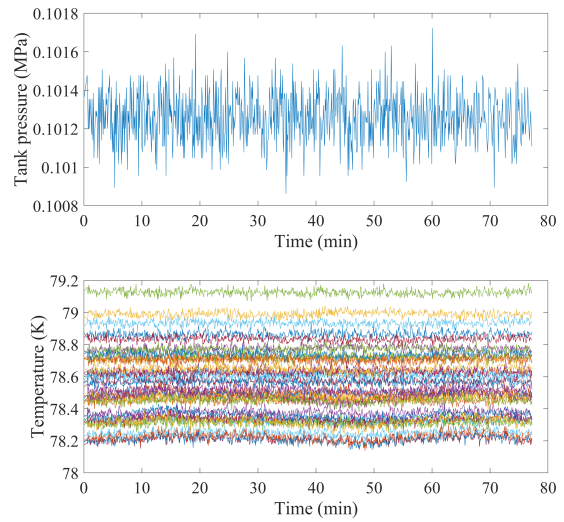


Fig. 5. Experiment measurements of pressure (top) and temperature (bottom) for calibration of 40 thermocouples

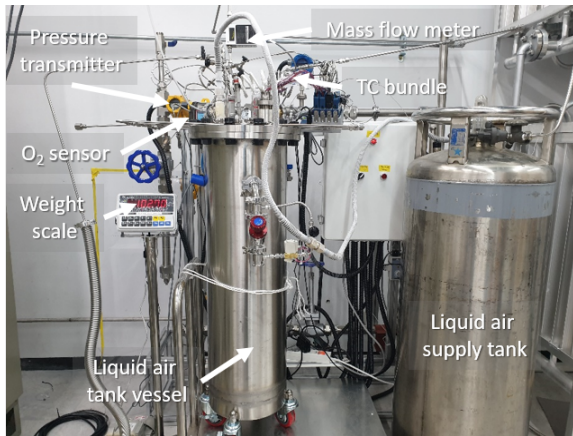


Fig. 3. Setup of liquid air tank stratification experiment

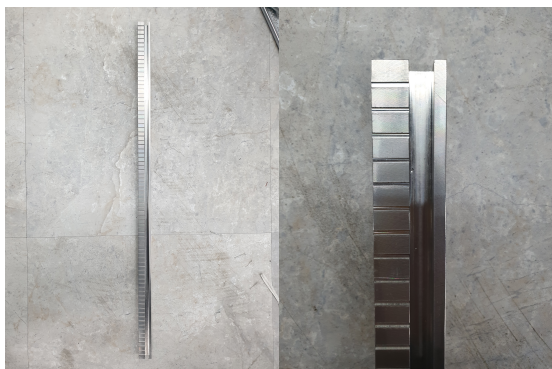


Fig. 4. SS304 bar machined for TC support inside the tank

The preliminary measurement results for the tank pressure and thermocouples are obtained for the purpose of TC calibration. The results are shown in Fig. 5, and they are obtained under constant pressure at 1 bara and set at 1×10^{-4} torr vacuum.

3. Summary and future works

The paper describes the experimental setup for investigating the tank stratification issue in the liquid air storage tank. This lab-scale test facility will provide meaningful data to discover the conditions under which stable tank stratification may occur.

Future works include conducting of the tank stratification experiment and analyzing the results. Furthermore, they will be used for evaluating the performance degradation due to tank stratification.

ACKNOWLEDGEMENT

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