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Development of dimensionless groups for heat and mass transfer in adsorbed gas storage

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A B S T R A C T

A new methodology for analyzing heat and mass transfer in gas storage via adsorption has been developed. The foundation behind the proposed methodology comprises a set of physically meaningful dimensionless groups. This paper presents a discussion regarding the development of such groups, based on the Buckingham-Π theorem, providing a fully normalized multi-dimensional formulation for describing transport mechanisms involved in adsorbed gas storage. Data from previous literature studies are employed for determining realistic values for the developed parameters. Then, a one-dimensional test-case problem is selected for illustrating the effect of the dimensionless parameters on the operation of adsorbed gas reservoirs. This problem is numerically solved, and the solution is validated against previously published literature data. The presented results demonstrate that higher heat of sorption values can lead to reduced discharge capacities if the increased heating is not properly removed, whereas larger Biot and Fourier numbers can increase the amount of gas recovered.

1. Introduction

The constantly growing worldwide demand for gaseous fuels such as natural gas and hydrogen has been motivating the development of efficient gas storage and transportation technologies. Currently, there are two main gas storage methods: compressed gas and liquified gas. Although these storage modes are well established, there are inherent drawbacks. Compressed gas has the disadvantage of working at high pressures, which require heavy reservoirs for transportation and high compression costs. On the other hand, liquified gas needs cryogenic temperatures and specialized equipment for re-gasification. In this scenario, a relatively new technology comes as a promising alternative: adsorbed gas. This alternative relies on loading the gas into porous sorbent materials and, while compared to the other alternatives, has the advantages of employing lower pressures and requiring no need for extreme temperature reduction. Wegrzyn and Gurevich [1] compared adsorbed natural gas storage with other technologies, providing estimates of costs associated to each technology.

In order to establish adsorbed gas as a commercially viable alternative, it is necessary that it be competitive with the currently available storage modes. However, this can only happen if an appropriate thermal design is achieved, since the sorption effect generates unwanted heating (and cooling) that significantly diminishes storage and recovery capabilities. This problem becomes more severe for hydrogen than natural gas since the latter can achieve higher energy storage performances. Sáez and Toledo [2] experimentally investigated the thermal effect resulting from the heat of adsorption on both charge and discharge performance of adsorbed natural gas storage systems, and the adsorption of methane on several different kinds of materials was studied by Sun et al. [3]. Because of the limitations in storage performance caused by thermal effects, there is a considerable need for heat transfer intensification in adsorbed gas reservoirs. In this context, a couple of solutions to remedy the problem have been proposed. Vasiliev et al. [4] numerically simulated the use of a heat pipe to reduce the unwanted thermal effects, and Yang et al. [5] proposed a solution which consisted of using a u-shaped heat exchanging pipe to supply heat to the central region of the storage vessel for reducing the unwanted thermal effects during discharge.

Regardless of the proposed solution strategy, a proper understanding of the heat and mass transfer mechanisms that occur within adsorbed gas reservoirs is required. As a result, a number of

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