

Unique Regeneration Steps for the Sorbent-Based Atmosphere Revitalization System Designed for CO₂ and H₂O Removal from Spacecraft Cabins

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ABSTRACT

An SBAR system for H₂O and CO₂ removal from spacecraft cabin air was studied both experimentally and theoretically. An emphasis was placed on its purgeless, deep vacuum regeneration step. Three evacuation steps were studied: 1) single ended depressurization (SED) through the feed end of the bed; 2) simultaneous dual ended depressurization (DED) through both ends of the bed; and 3) simultaneous triple ended depressurization (TED) through both ends of the bed and a port located at some axial position. TED resulted in a lower average bed pressure at the end of evacuation compared to DED, which, in turn caused more CO₂ to be removed. An optimal third port location also existed. The use of TED should allow the SBAR bed size to be reduced.

processes, but it has also greatly increased in capability with respect to the breadth of operational configurations it has simulated. DAPS is continuing to be developed with respect to improving its quantitative predictive capability.

In particular, the teams at USC and the MSFC have been designing a unique life support system that epitomizes the extremes of pressure swing adsorption (PSA) process design and operation. This PSA process is called the sorbent-based atmosphere revitalization (SBAR) system. They are developing SBAR for NASA for CO₂ and H₂O removal from spacecraft cabins. Knox and co-workers [3] have been carrying out prototypic SBAR experiments, some of which have been based on predictions from DAPS; others have been used to further validate and help quantify the productions from DAPS.

INTRODUCTION

Over the past decade Ritter and co-workers at the University of South Carolina have developed a very robust dynamic adsorption process simulator (DAPS) [1]. Recently, they have been using DAPS in support of extraterrestrial adsorption process design efforts on-going with Knox and co-workers at the Marshall Space Flight Center [2]. DAPS has not only greatly enhanced their understanding of the underlying physics of such

This SBAR system consists of a 2-bed 4-step 2-layer PSA system that operates between atmospheric pressure and space vacuum, evacuates from up to three ports in the column simultaneously, experiences choked flow conditions during pressure changing steps, and experiences a continuously changing feed composition, as it removes metabolic CO₂ and H₂O from a closed and fixed volume, i.e., the spacecraft cabin. Clearly, this PSA or SBAR process is very unique and represents a challenge to any dynamic process model. Nevertheless,

over the past four years, DAPS has been upgraded significantly and is now capable of modeling this SBAR system with reasonable accuracy.

Features added to DAPS include: the ability to handle multiple absorbent layers in each bed, the ability to account for pressure drop in the column, the ability to simulate entering and exiting flows and predicting real-time pressurization and depressurization rates with valve equations, the ability to handle choked flow conditions, the ability to handle very large pressure ratios and hence velocities associated with deep vacuum systems, the ability to model a closed loop system by recirculating the effluents leaving the column back to the feed being fed to the column through a large, fixed volume, such as the spacecraft cabin, the ability to pressurize and depressurize simultaneously from multiple ports along the column, the ability to equalize between multiple pairs of columns, and the ability to equalize simultaneously from both ends of pairs of columns. These changes make the latest version of DAPS very applicable to the SBAR system under consideration by NASA. Additional changes planned in the near future will make DAPS applicable to a wider variety of adsorption technologies of interest to NASA.

Fixed bed adsorption technology designed for extraterrestrial applications has other features that also make it unique compared to its earthbound counterparts. For example, since vacuum is readily available in space, it is the only practical means available to lower the partial pressures of the adsorbates in the bed to desorb them from a nearly saturated adsorbent. In contrast, on Earth dilutant gases are cheap. So, they are generally used as purge, which also effectively lowers the partial pressures of the adsorbates in the bed to desorb them. Dilutant gas can certainly be used in spacecraft applications; however, the need for a continuous supply of it would be exorbitantly expensive. As a result, to foster bed regeneration in extraterrestrial applications extremely large pressure ratios are used in lieu of relatively high purge flows in earthbound applications.

One of the major concerns associated with this purgeless approach is the effectiveness of just a pressure change to regenerate the bed. Once the bed reaches the lowest pressure possible by exposing it to the vacuum of space, and in the absence of any major mass transfer resistance from the adsorbed phase to the gas phase inside the bed, the bed essentially reaches an equilibrium state with no further regeneration possible. In this situation it is advantageous to evacuate the bed as rapidly as possible to reach this low pressure as quickly as possible. The faster this can be done, the shorter the cycle time, the smaller the required bed size, all while providing the same performance. This notion is expounded on later in the paper.

With bed regeneration in mind, the objective of this paper is three fold. First, a description of NASA's SBAR PSA system is provided. An emphasis is placed

on the alternative regenerative steps that NASA has developed to further improve performance. These steps are dual and triple ended evacuation steps compared to the traditional single ended evacuation steps. Second, results are presented that show validation of DAPS against NASA's experimental data from a dual ended evacuation system. Third, results from DAPS are used to discuss the role of these unique multi-port regeneration steps on the performance of the SBAR system in terms of H_2O and CO_2 removal efficiencies.

PSA (SBAR) PROCESS DESCRIPTION

The 2-bed 4-step PSA cycle depicted in Figure 1 includes the following cycle steps. The feed (F) step is carried out at just above atmospheric pressure (P_H). The (D) depressurization or evacuation step is carried out in two steps: a single ended depressurization (SED) step from P_H to a lower intermediate pressure (P_I), followed by either a double ended depressurization (DED) step or triple ended depressurization (TED) step from P_I to a lower pressure (P_L). DED is carried out simultaneously through both ends of the bed, while TED is carried out simultaneously through those ends plus an additional port located somewhere along the bed. Finally, a feed pressurization (FP) step from P_L to P_H is carried out.

While one bed undergoes the FP and F steps, the other bed undergoes the D steps. The heavy products (H_2O and CO_2) are removed from the system during the D steps. The light product (mainly N_2 and O_2) is recovered during the F step.

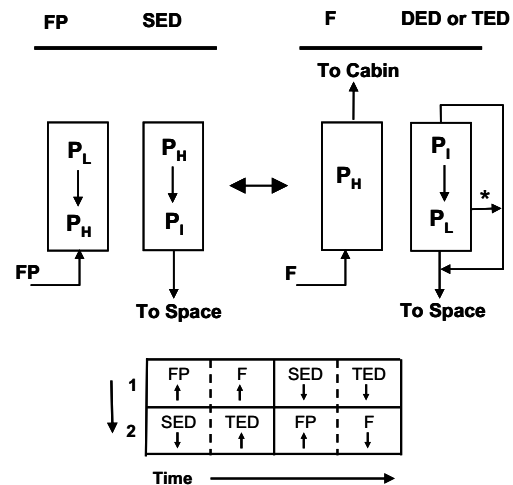


Figure 1. Schematic of the 2-bed 4-step PSA cycle used by DAPS in the parametric study with a layered bed. F = feed; SED = single ended depressurization; DED = double ended depressurization; TED = triple ended depressurization; FP = feed pressurization; P_L = low pressure; P_H = high pressure; P_I = intermediate pressure. The starred steam indicates the unique third exit flow used in TED.

The periodic state process performance of this PSA cycle is judged by the H_2O and CO_2 removal. The H_2O or CO_2 removal is defined as the amount of H_2O or