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# A switching decentralized and distributed extended Kalman filter for pressure swing adsorption processes

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ABSTRACT

A continuous-discrete Distributed and Decentralized Switching Kalman Filter (DDSKF) is designed for estimation of spatial profiles in Pressure Swing Adsorption (PSA) processes. The introduced observer is an integral part of the control strategy of hybrid systems in general and PSA systems in particular. A reduced order model is developed based on the mechanistic model of the process. The sensors are optimally located and observability of the process is studied. The proposed observer is used to estimate the spatial profiles of various states of a two-bed, six-step PSA system used for production of pure $H_2$ from a $H_2$ $-CH_4$ gas mixture. The spatial profiles of the system have been estimated using the proposed observer quite accurately and rapidly based on noise corrupted measured temperature and pressure of a few points in the process.



## Introduction

Pressure Swing Adsorption (PSA) is a well-known and widely-used technology for separation and purification of gas mixtures. PSA processes are autonomous distributed parameter switching systems. During the switching modes of the process, separation of gas species is performed by cyclic adsorption-desorption at higher and lower pressures. Recently, control of PSA processes has attracted more interest, although a few studies have been reported in the literature [5,14,25]. One of the main decision variables in PSA processes is product purity, whereas having the concentration profile is significant, but its measurement requires large sampling time and it is available only at the end of adsorption beds. On the other hand, the number of pressure and temperature measurements is very limited in PSA processes. This leads to one of the most important challenges in Advanced Process Control (APC) methods for these processes, due to the loss of information corresponding to the spatial profiles along the

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adsorption beds. Hence, design of an observer for the reconstruction of the profiles of pressure, temperature, and concentration in particular, would be an utmost necessity for efficient control and monitoring of the PSA processes.

Design of state observer for adsorption systems was the topic of a few studies. Mangold, Lauschke et al. [20] proposed an observer based on a simplified linear distributed parameter model of an adsorption bed. The observer states were corrected based on physical and heuristic considerations. Yang, Rathbone et al. [32] designed an extended Kalman Filter based on a linear low-order model for breakthrough estimation using temperature measurements in an ion-exchange adsorption column. Bitzer and Zeitz [6] used a nonlinear distributed parameter observer for estimation of spatial profiles of a PSA process. Their observer followed Luenberger's idea and the observer gain was calculated intuitively instead of solving Riccati equation. Won and Lee [29] presented a nonlinear observer with adaptive grid allocation to estimate the spatial profiles in adsorption beds in the presence of measurement noise. They have used a simplified Kalman filter in which its observer gain is a static function of the state variables to overcome the time consuming procedure of standard Kalman filter.

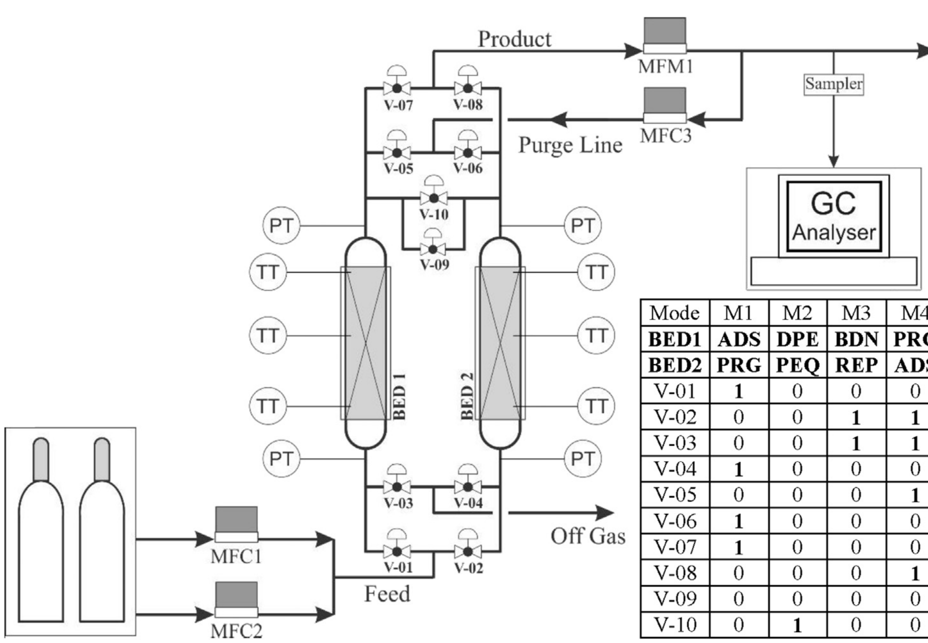
Here, a continuous-discrete Distributed and Decentralized Switching Kalman Filter (DDSKF) is proposed for reconstruction of spatial profiles in PSA processes for future usage in a hybrid control system of PSA processes. Process uncertainties and measurement noise are unavoidable in practical applications. In addition, regarding the distributed nature of adsorption beds, even the use of Reduced Order Model (ROM) leads to a large number of state variables. Consequently, determination of dynamic observer gain in a centralized Kalman filter is time consuming, which brings up various problems in real-time implementation of the observer. Several distributed and decentralized Kalman filter methods have been proposed in the literature [12,18].

In the present study, a PSA process for $H_2$ purification from a $H_2$–$CH_4$ gas mixture is investigated. A detailed model of an adsorption bed is developed, and then its ROM version is obtained by Orthogonal Collocation Method (OCM). Observability analysis is conducted by a graphical approach [16] and pressure and temperature sensors are optimally located by numerical simulation, test of independence, and insights gained from both numerical simulation and process operation. Numerical simulation is used for investigation of both dynamic behavior of the PSA plant and performance of the proposed observer along with the plant model.

## PSA process

PSA processes are autonomous distributed parameter hybrid systems. Consider the two-bed, six-step PSA system, illustrated in Fig. 1 along with the corresponding scheduling table for arrangement of the solenoid valves in the switching modes of the process. The adsorption beds contain activated carbon as adsorbent used for separation of $H_2$–$CH_4$ gas mixture, which is a simple gas mixture in compare to the conventional gas mixtures used in $H_2$-purification applications [17,21,31]. The objective is to obtain a high purity $H_2$ product from a $H_2$–$CH_4$ mixture whose $H_2$ purity is 70%. Each cycle of the considered PSA process consists of six sequential steps that are described below:

*Step 1. Adsorption (ADS)*: The binary gas mixture of $H_2$–$CH_4$ enters from the bottom of the bed as the feed stream. The gas flows through the bed with inlet pressure of 7.0 bara and temperature of 303 K. During the adsorption step, $CH_4$




| Mode | M1 | M2 | M3 | M4 | M5 | M6 |
|---|---|---|---|---|---|---|
| **BED1** | **ADS** | **DPE** | **BDN** | **PRG** | **PEQ** | **REP** |
| **BED2** | **PRG** | **PEQ** | **REP** | **ADS** | **DPE** | **BDN** |
| V-01 | **1** | 0 | 0 | 0 | 0 | **1** |
| V-02 | 0 | 0 | **1** | **1** | 0 | 0 |
| V-03 | 0 | 0 | **1** | **1** | 0 | 0 |
| V-04 | **1** | 0 | 0 | 0 | 0 | **1** |
| V-05 | 0 | 0 | 0 | **1** | 0 | 0 |
| V-06 | **1** | 0 | 0 | 0 | 0 | 0 |
| V-07 | **1** | 0 | 0 | 0 | 0 | 0 |
| V-08 | 0 | 0 | 0 | **1** | 0 | 0 |
| V-09 | 0 | 0 | 0 | 0 | **1** | 0 |
| V-10 | 0 | **1** | 0 | 0 | 0 | 0 |

**Fig. 1 – Schematic of a two-bed, six-step PSA plant for separation of $H_2$–$CH_4$ gas mixture and the corresponding scheduling table of the solenoid valves in the switching modes of the process.**

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