Conference Paper

PSA-Stage Features of the Hybrid Membrane-Sorption Oxygen Concentrator

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Abstract

The paper considers the principle of the organization of the hybrid membrane-sorption oxygen concentrator and the work of the PSA stage of the hybrid system. The use of hybrid membrane-sorption gas separation systems can significantly reduce the energy consumption of plants, as well as to neutralize such disadvantages as contamination of the product flow by the products of abrasion of sorbents, through the use of highly selective polymer membrane, and the restriction on the oxygen concentration when using a single membrane stage, through its use after the PSA stage. In this paper, we propose an arrangement for the operation of the PSA stage of a hybrid system consisting of three adsorbers and providing a constant product flow of the PSA stage necessary to ensure continuous feed flow to the membrane stage of the system. Each of the adsorbers in this system passes through three main stages: filling, displacement (adsorption), and discharge (desorption). Moreover, the filling is not from the compressor, but part of the product flow of the displaced adsorber. The results of the operation of the system organized by the proposed method are compared with the results of the operation of modern gas separation systems on the market.

Keywords: Sorption, air separation, pressure-swing adsorption, PSA, hybrid technologies, oxygen concentrator, recycling, oxygen

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1. Introduction

Most often, one of three main separation methods is used to separate air into components: membrane, sorption or cryogenic. The cryogenic method of air separation is the most popular in the industry due to the high purity of the products obtained, the possibility of simultaneously obtaining several separation products in the liquid and solid phases and the reliability of the equipment [1]. However, low profitability, high capital and operating costs, as well as weight and size characteristics of the plants do not allow efficient use of the cryogenic method with small and medium volumes of oxygen production [2]. The sorption method makes it possible to obtain high productivity and enrichment at relatively low capital costs, ease of operation and rapid start-up of the system [3] the disadvantages of the sorption method include a low degree of extraction and contamination of the product flow by the products of the sorbent abrasion. Membrane systems of oxygen production have small dimensions and time of operation, simple design, high selectivity and recovery degree [4], while the membrane method does not allow obtaining an oxygen concentration above 50% when using a single-stage gas separation system. Thus, the disadvantages of the membrane method of obtaining oxygen include low enrichment and productivity, high energy costs when using recirculation schemes. Since each of the traditional methods of air separation into components has both advantages and disadvantages, in recent years much attention has been paid to hybrid gas separation technologies in air separation [5].

More often, speaking of hybrid technologies for air separation, we have in mind membrane-sorption systems [6, 7]. The use of hybrid membrane-sorption gas separation systems can significantly reduce the energy consumption of plants [8], as well as to neutralize such disadvantages as the contamination of the product flow by the products of the sorbent abrasion, through the use of a highly selective polymer membrane, and the restriction on the concentration of oxygen when using a single membrane stage, through the use of it after the PSA stage.

Of practical interest is the development of portable oxygen concentrators, suitable for powering artificial lung ventilation devices, based on hybrid membrane-sorption gas separation systems.

2. Materials and Methods

One of the main tasks that must be solved in the construction of the hybrid membrane-sorption system is the task of providing a stationary flow of the PSA product of the stage to ensure a continuous supply of feed to the membrane stage. Figure 1 shows a schematic diagram of the proposed hybrid system.

The first stage of separation uses the PSA system (1), the second stage of separation uses the membrane module (2). Feed flow PSA stage is carried out simultaneously by two flows: the external gas flow supplied from the compressor (F_c), and the flow of the retentate W of the membrane stage. The product flow of the step PSA (P') is fed to supply the membrane stage of the hybrid system, the product flow P of which is output to the consumer. The retentate flow of the first stage of separation (W'), depleted by the target component is removed from the system into the atmosphere.

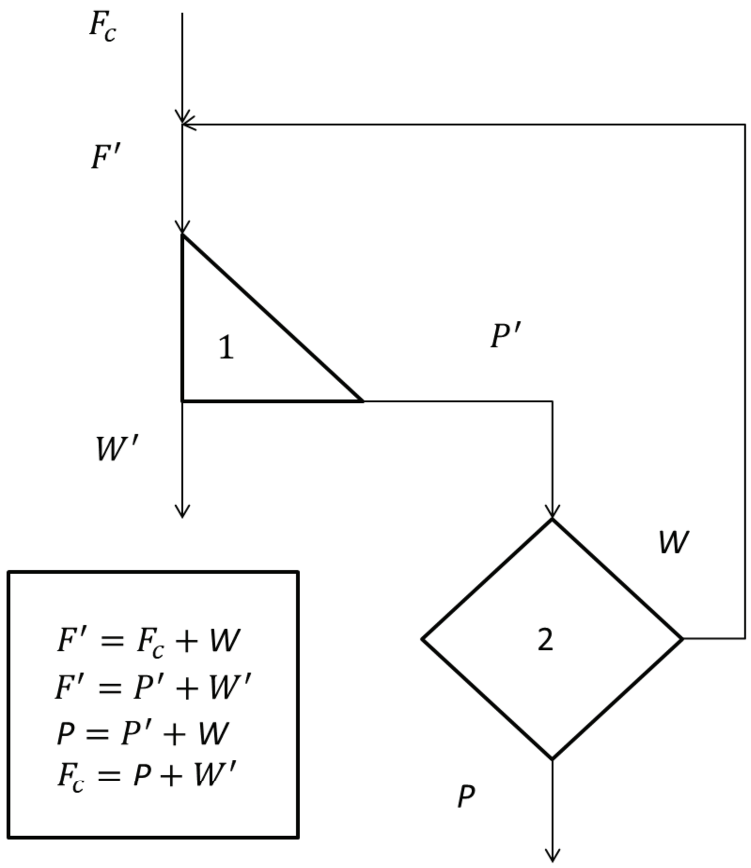

Figure 1: Schematic diagram of the hybrid membrane-sorption oxygen concentrator: 1-PSA stage, 2-membrane stage.

To solve the problem of providing a steady flow of the membrane stage of a hybrid membrane sorption system, it is proposed to use the three-adsorbed PSA system with regeneration of the adsorbent at atmospheric pressure.

The operating parameters of the PSA stage are: a flow of consumed air of 100 l / min, a PSA product flow of 10 l / min, a feed flow pressure of 8 atmospheres, a product flow pressure of 6 atmospheres, an adsorbent regeneration pressure of 1 atmosphere.

To compare the efficiency of the PSA stage, organized by the proposed method, an oxygen PSA system using sorbent regeneration at atmospheric pressure [9], an oxygen membrane module of Air Products [6] and a modern sorption gas separation system [3], capable of obtaining oxygen of purity of 94% were taken. The comparison was carried out at operating parameters of the proposed PSA step and the division ratio of the flux of the membrane is 0.1.

3. Proposed Scheme

The organization of the PSA stage of the hybrid membrane-sorption system consisting of three adsorbers and providing a constant product flow of PSA stage is shown in Figure 2(a).

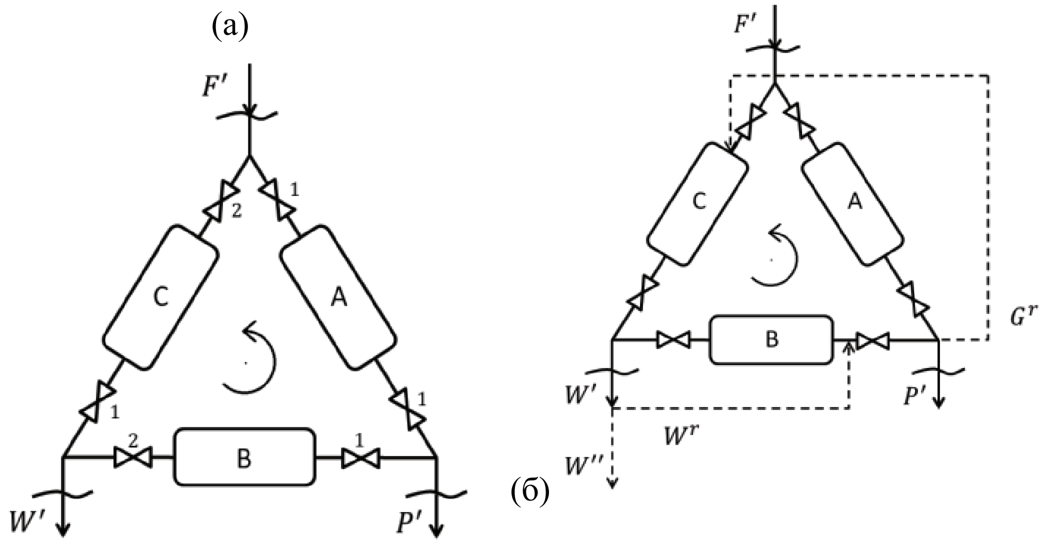

Figure 2: Scheme of the operation of the three-absorber PSA system without the use of purging and leveling (a) and with their use (b).

The PSA stage of the system works as follows. Each of the adsorbers of the system passes through three main stages: filling, displacement (adsorption) and discharge (desorption). The filling is not from the compressor, but part of the product flow of the displaced adsorber. Thus, the compressor flow is used only to displace the product flow. At the moment when the adsorber C passes the reset stage, part of the stream from the adsorber A enters the adsorber B, thereby ensuring its filling, the other part of the stream from the adsorber A is discharged to the second stage of the system. Thus, a constant product flow of the PSA stage is achieved.

This system of organization of the PSA stage allows for the introduction of additional stages: counterflow purging and equalization (Figure 1 (b)). Part of the gas discharged from the adsorber C to the atmosphere at the beginning of the discharge stage is discharged to the adsorber B. The adjustment stage thus carried out will allow to preserve part of the target component discharged into the atmosphere, which will increase the extraction degree of the target component and reduce the time of filling of the adsorber B. The flow entering the filling of the adsorber B from the adsorber A during the equalization stage is redirected to the outlet of the adsorber C to conduct a counterflow purge of the sorbent. These additional steps will increase the productivity of the process and the purity of the product.

4. Results and Discussion

In the course of the research, an experimental study of the PSA stage of the hybrid membrane sorption system step was carried out. The results are compared with the results of the operation of the oxygen membrane module, the PSA system with regeneration of the adsorbent at atmospheric pressure and the modern industrial PSA plant. Table 1 shows the results of air separation using the methods described.

Table 1

	Membrane module «Air Products»	PSA with atmospheric regeneration	Hybrid membrane-sorption system	PSA with counterflow purging
$F(O_2)$, L/min	21,00	21,00	21,00	24,78
$F(N_2)$, L/min	79,00	79,00	79,00	93,22
P(O2), L/min	4,70	3,50	7,20	9,40
P(N2), L/min	5,30	6,50	2,80	0,60
R(O2), L/min	16,30	17,50	13,80	15,38
R(N2), L/min	73,70	72,50	76,20	92,62
Recovery O2	0,22	0,17	0,34	0,38
Recovery N2	0,93	0,92	0,97	0,99

It can be seen that the greatest oxygen recovery is achieved in a system using an equalization stage and a counterflow purging in the regeneration, while the recovery in the proposed PSA system differs from the PSA system with equalization and counterflow purging by 9.5%. The oxygen recovery factor for the PSA system with regeneration at atmospheric pressure is 2 times lower than for the proposed system. The membrane module operating in the specified parameters showed an oxygen recovery result of 35% lower than the proposed PSA system. The oxygen concentrations obtained as a result of the study: a PSA system with counterflow purging and a 94% equalization stage, a PSA system organized by the proposed method of 72%, a membrane module of 47% and a PSA system in 35% regeneration at atmospheric pressure.

5. Summary

The proposed scheme for organizing the PSA stage allowed to provide the membrane stage of the system with a steady feed flow. The obtained results showed the effectiveness of the proposed method of organizing the PSA stage of the hybrid membrane-sorption oxygen concentrator, when enriching the mixture with oxygen. The oxygen recovery obtained at the stage is inferior to modern gas separation systems operating by the PSA method by no more than 10%. At the same time, the introduction of a stage of equalization and counterflow purging in the work will reduce this gap.

Acknowledgements

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