THE EFFICIENCY OF THE COUNTERCURRENT BLOWDOWN IN THE MEMBRANE-SORPTION SYSTEM WITH THREE ADSORBERS

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Abstract. Hybrid membrane-sorption systems are used to solve the problems of the gas mixtures separation, as air enrichment with oxygen or compressed air drying. Investigation of the waste flow of the PSA stage showed that the flow contains a significant amount of the target component. Thus, it is possible to increase the efficiency of the plant without additional energy costs by implementing a scheme, in which waste flow is used for expulsion. Considered scheme with the sorbent regeneration by the method of blowdown is applicable for various gas mixtures separation, in which it is necessary to separate out the low-sorption component. A demanded application of this scheme can be the solution of the air drying problem.

1. Introduction
The gas drying is one of the actual gas separation problems. In many technological procedures operating on the compressed gas, for example, wherein air is divided into nitrogen and oxygen, moisture adversely affects the processes occurring in them and can disserve the system. To solve these problems, membrane and adsorption technologies are often used. These technologies allow obtaining the necessary gases directly at the point of use. Due to the continuous development of the membrane and sorption technologies, the devices created on their basis become more mobile and compact, which expands the field of their application.

The combinations of different methods have been applied for better results. The investigations of the hybrid systems [1-3] has shown that their use is more effective than the use of individual methods. The combination of several methods that operate on different physical principles and in different technological modes has difficulties, which, as a rule, are connected with the work coordination of the individual modules and the choice of the optimal operating mode.

A scheme of a membrane-adsorption plant for air enrichment with oxygen is described in [4]. The system is designed for the air production enriched with oxygen. Such an installation can be used as a feed supply for medical oxygen equipment. However, the system can be improved to solve other problems, for example when choosing the necessary sorbent, it can be used for the drying of wet compressed gas.

The use of a adsorption unit with three adsorbers allows to provide the membrane module with a constant feed flow. This is achieved due to the coincidence of the number of stages, the duration of which is approximately the same, in the cyclogram and adsorption columns. At any one time, one of the columns is at the stage of producing a stream enriched in oxygen. The other two columns are in the stages of filling and regeneration.
2. Main body

Each adsorption column operates in a specific cycle, which includes several stages. In the simplest version, the cycle consists of two stages: the production of the target component and regeneration. The effectiveness of the production stage largely depends on how effectively the regeneration stage has passed. Several methods for the adsorbent regenerating are described in [5]. Each of these methods has its own peculiarities of application. So, regeneration due to the heating of the adsorbent is very effective, but significantly increases the cycle times, since the process of heating and then cooling of the sorbent takes a long time. Regeneration by pressure reducing can be conducted much faster.

The regeneration by pressure change underlies plants operating by the method of pressure swing adsorption (PSA) [6]. The essence of this method is in the rapidly changing stages of adsorption-desorption. The adsorption stage proceeds at elevated pressure, and the desorption stage under reduced pressure. The faster the adsorption stage passes, the higher the concentration of the desired component can be obtained. However, at short adsorption cycles and to the end of the production step the residual concentration of the target component is still high in a gas phase of adsorber. During the regeneration stage, this gas enriched with the target component is dropped into the atmosphere.

Figure 1 shows the graphs of the concentration dependencies in the vented flow on the pressure in the adsorber. Each curve corresponds to a different preliminary saturation of the sorbent with oxygen. In order to achieve different initial conditions, the sorbent layer was blown with air with different concentrations of oxygen until equilibrium state was established, i.e. up to the time when the flow rate and the composition of the gas supplied to the adsorber will be equal to the flow and to the gas composition leaving the adsorber. After that, the work of the adsorption column in the PSA plant was simulated. For some time, air was blown into the adsorber under operating pressure for oxygen production.

![Figure 1. The graph of the concentration dependencies in the vented flow on the pressure in the adsorber](image)

From the graphs in Figure 1, it can be seen that desorption has several distinctive stages. Thus, in the first stage, the concentration of the weakly-sorbed component (oxygen) remains constant and equals to the equilibrium concentration established before the beginning of the displacement stage. In the second stage, the concentration of the weakly-sorbed component is sharply reduced. This happens due to the active desorption process of the highly-sorbed component (nitrogen). The desorbed nitrogen is carried away with the gas flow created by the gradient of concentration. In the third section, the concentration of the weakly sorbed component also decreases, but this section has the peculiarity. The desorption curves are close to each other, independently of the initial equilibrium concentration.

To improve the efficiency of the system, various methods are used. So often the stage of the pressure equalizing between the adsorber, which has passed the regeneration stage by the pressure drop, and the adsorber, in which the production stage has been already completed, is used.
Equalization of the pressure allows reducing energy costs associated with the pressure growth in the adsorber [7]. In addition, as can be seen from Fig. 1, the adsorber will be filled with a gas enriched with the target component.

It is known that in order to achieve high concentrations of the target component, the stage of countercurrent expulsion has the great importance, which allows to regenerate the adsorbent deeper. The expulsion of the sorbent is carried out by a gas enriched with the target component, in the direction opposite to the adsorption flow. In this case, the regeneration takes place due to a decrease in the partial pressure of the highly-sorbed gas.

The objectives of the countercurrent expulsion are:
- The desorption of the highly-sorbed component and its removal from the adsorber with the gas flow;
- Creation of the most profitable for adsorption an initial concentration distribution between phases.

For investigation of the expulsion process, 100% oxygen was supplied to the input of the adsorber at a different flow rate. The output of the adsorber was connected with the atmosphere, while the main parameters of the output flow were recorded (concentration and the flow rate).

Figure 2 shows the time variation of the oxygen concentration in the output gas at different expulsion velocity.

![Figure 2. Oxygen concentration dependence in the outlet gas on the time at the different expulsion velocity: 1 – 2.5 l/min; 2 – 2 l/min; 3 – 1.7 l/min; 4 – 1.2 l/min;](image)

The presaturation of the adsorbent with the nitrogen was the same. It is corresponded to the value at which the adsorbed nitrogen was in equilibrium state with the gas phase at a pressure of 1 atm. and an oxygen concentration of 8%. This composition of the gas phase is achieved during desorption by reducing the pressure to atmospheric (Figure 1).

On the resulting graphs, two characteristic areas can be distinguished. The first section, where the concentration remains constant, corresponds to the concentration of oxygen in the preceding stage. The presence of this area indicates that the state between the gas phase and certain sorbent layers, including the last in the direction of the gas flow, is close to equilibrium. The second section is characterized by a regular fall in the nitrogen content in the output gas flow.
Figure 3. The graphs of the waste and feed flow dependence on time at the different expulsion velocity:
1 – 7.4 l/min; 2 – 5.4 l/min; 3 – 3.5 l/min; 4 – 1 l/min.

As it can be seen from the obtained results, that at the initial time the waste flow rate is significantly higher than the feed flow rate. This occurs due to the fact that the incoming oxygen disturbs the equilibrium state between the solid and gaseous nitrogen phase, as a result the process of nitrogen desorption from the surface of the sorbent starts actively. As the desorption front moves along the sorbent layer, the flow rate of the waste flow approaches to the value of the feed flow. When the desorption front reaches the outlet, the flows become equal, and at the outlet the oxygen concentration reaches the level of 100%.

Experiments, had been carried out at different flow rates, showed that the desorption degree at a constant temperature is approximately independent of the flow velocity and depends only on the amount of the expulsion flow.

3. Conclusions

The characteristics investigation of the sorption unit of the hybrid membrane-sorption system with three adsorbers was carried out. This characteristics are connected with sorbents regeneration.

In the framework of the task, experiments were carried out to investigate the waste flow of the sorption unit at pressure dump in the adsorption-desorption cycle as well as at the expulsion of used sorbent by oxygen flow.

As a result, it was shown that the gas dropped during the desorption stage into the atmosphere is enriched with the target component, so, it is used to fill another adsorber in order to increase the efficiency of the system. However, experiments have shown that the sorbents expulsion is an effective method of sorbents regenerating. Thus, instead of filling the adsorber, the gas flow can be sent to the adsorber expulsion and the part of the nitrogen will be removed from the sorbent layer and the gas phase. This method of regeneration can be used in schemes with three or more adsorbers. Since two adsorbers are involved in the expulsion process, and therefore a two-adsorber scheme will not allow to obtain the constant flow.

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