Hybrid solutions of compressed gas drying

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Abstract. In this paper, the schemes of membrane-refrigeration drying and vapor removal from compressed gas are considered for use in industry. The efficiency analysis of the hybrid membrane-sorption technologies usage for gas drying was carried out. The scheme of the hybrid steam separator with two recirculation circuits is proposed, and this scheme consists from three stages. The first stage of the scheme is represented by PSA block, consisted from three adsorbers, which are filled with a solid zeolite. These adsorbers are good in water vapor absorption. The second stage is a membrane module, which is fed by waste flow of the PSA stage. Herein membrane material has a significant value of the permeability for water vapor. The third stage – refrigerator is needed for condensing of water vapor from a gas flow, permeated through membrane. Water vapor is condensed and removed from the system while dry gas is returned to the system. According to proposed scheme of hybrid system organization, deep drying can be performed without pressure loss and without change in the components of the flow.

1. Introduction

Dry air has found its application in many branches of industry and agriculture, in exact mechanical engineering, pharmaceuticals and medicine, aviation and shipbuilding. Currently on an industrial scale, the drying air is carried out by two main methods: adsorption and refrigeration. The nature of the refrigeration method is to cool the air to the required dew point. However, this method is quite energy-intensive and does not allow reaching low dew points. The most popular drying method is the adsorption method based on cyclic processes. The essence of the method lies in the alternation of adsorption and desorption processes carried out at different temperatures or pressures. The most widely used method of PSA (Pressure Swing Adsorption), proposed by C. W. Skarstrom [1]. A distinctive feature of this method is that adsorption and desorption are carried out at a constant temperature, and the partial pressures of the adsorbed components with adsorption are greater than when desorbed. However, the PSA method has a significant drawback, for the regeneration of the sorbent, it is necessary to use either additional pumps or a significant part of the product flow that is returned to the system to restore the properties of the sorbent. A lot of papers have been devoted to the problem of returning the flow to the regeneration of the sorbent [2, 3].

In recent years, special attention has been paid to the membrane technology of gas drying. One of the advantages of using membrane technology in the drying of compressed gases is the ability to extract readily penetrating impurities simultaneously with the removing of water vapor, as well as the separation of gas mixtures into components. An example is the task of preparing natural gas for
liquefied [4]. In addition, such schemes are used to purify natural gas from CO2 proposed in the patent [5].

2. Statement of the problem
Practical interest in the field of compressed gas drying in the coming years will be the development and creation of drying systems based on hybrid membrane-adsorption systems, which in the future should reduce the energy consumption of compressed gas drying systems. One of the variants of membranes that are supposed to be used in such systems of drying is PVTMS (vinyltrimethylsilane) membrane having a rather high permeability for water vapor.

As examples of a hybrid drying system using a membrane vapor separator, one can consider the schemes of open and closed single-module steam separator and a closed two-module system.

Figure 2 shows the schematic diagram of a single-module membrane steam separator of open type. The scheme works as follows. The input flow F by compressor 1 is compressed and fed to the membrane module 2. A pressure drop is created by pump 3 connected to the permeate of the membrane module. Freely penetrating water vapor permeates through the membrane material and enters the refrigerator 4, where condensation and moisture removal take place - flow C. Dry air that doesn’t pass through the membrane (flow P) is supplied to the consumer.

The main disadvantage of open-type systems is the presence of the flow W coming out of the dryer, it is often thrown out, which reduces the energy efficiency of the system as a whole. However, the concentration of water vapor in such a flow after passing through the refrigerator can be significantly lower than in the flow F. Therefore, to preserve the flow W in the system and increase the overall efficiency of the system, closed circuits are more often used. The schematic diagram of the closed-type single-module membrane steam separator is shown in figure 3. Its peculiarity is that the flow W is not output from the system, but is returned to the input of compressor 1. This solution significantly improves the efficiency of the drying process with a single membrane steam separator. Additionally, in a system organized such method in the future, it is possible to get rid of the pump 3 using a compressor 1 to create a differential pressure.

To increase the efficiency and depth of drying, it is also possible to use the scheme of a two-module closed-type steam separator with two condensers, shown in Fig. 4. In such a drying system, the dehydrated gas in the first membrane module enters the second membrane module 4 where deeper gas drying takes place. Thus, using two consecutive membrane separators it is possible to achieve deeper degrees of drying. In addition, the system is organized in such a way that the permeates of both membrane elements are connected to the input of the compressor, which ensures a differential pressure them. However, due to the fact that the permeate of the membrane separator 3 is more moist with respect to the permeate of the membrane separator 4, it is necessary to install a second capacitor
thereon. Condenser 1 allows pre-drying of compressed air and prevents condensed moisture from entering the membrane module.

![Figure 3](image1.png)

**Figure 3.** Schematic diagram of a single-module closed-type membrane steam separator

![Figure 4](image2.png)

**Figure 4.** Schematic diagram of a two-module closed steam trap with two condensers.

However, the membrane direction is not the only promising direction in the field of gas drying. In this paper propose a scheme of a hybrid system for drying. The essence of hybrid methods is the simultaneous use of several methods of drying to improve the energy efficiency of the process, its productivity and purity of the product. In this paper, we consider a hybrid system consisting of a refrigerator, adsorption and membrane drying blocks.

The proposed hybrid system consists of two drying stages. At the first stage of the system, the three-adsorption PSA system is used as the main drying block. The second stage used a closed-type membrane steam separator. The main feature of the proposed hybrid system is the use of the flow the dried by membrane steam separator to regenerate the sorbent on the PSA stage of the system. This scheme allows solving the problem of the return of the product flow of the PSA system for the regeneration of the sorbent.

### 3. Results and discussion

The first stage of the scheme is represented by a PSA block consisting of three adsorbers filled with a solid zeolite, which absorbs water vapor well. The second stage of the scheme is a closed-type membrane steam separator, to which the wet flow of the PSA stage is fed. The membrane material of which the membrane module is composed, has a high water vapor permeability. A schematic diagram of a hybrid membrane-adsorption drying system is shown in Figure 5.

The scheme is designed for drying compressed gases by means of sorption and membrane technologies. The main working element of the scheme is the sorption block, which is represented by three adsorbers filled with a granular adsorbent. The work on gas drying in adsorbers is performed alternately, thereby it is possible to achieve a constant in time and pressure of the flow. During the drying of the gas with one adsorber, the others are on the step of regeneration and raising the pressure.

Dehumidification is carried out under high pressure, so the pressure rises in the adsorber before passing through it moist air. Adsorption of moisture from the gas stream is carried out during its transmission through the layer of regenerated sorbent. After the sorbent consumes its sorption resource, the gas on the drying starts to be fed to a pre-prepared adsorber, in which the operating pressure is set, and the adsorbent has passed the stage of regeneration.

The sorption stage of the system, consisting of three adsorption columns, operates in a cyclic mode. In one cycle of adsorber passes three steps: filling, production (displacement) and discharge (regeneration). A similar organization of work for the PSA system is described in detail in [6] with respect to the separation of air into components.

The step of regeneration of the spent sorbent is carried out in several stages. The first stage of regeneration is to reduce the pressure in the adsorber by discharging gas into the membrane vapor separator. In the second stage, the adsorber is purged with the dried gas supplied from the membrane
module. During purging of the spent sorbent with dry air, moisture is desorbed from its surface and is carried away with a dry stream making it wet.

![Schematic diagram of a hybrid membrane-adsorption system for drying compressed gas.](image)

**Figure 5.** Schematic diagram of a hybrid membrane-adsorption system for drying compressed gas.

The wet flow after the regeneration step of the sorbent is sent to the membrane module where it is dried by the membrane method. The gas and moisture that has passed through the membrane enters the condenser where the gas and moisture are separated. Moisture is removed from the system, and again the dehumidified gas returns to the feed stream of the membrane module. Thus, a closed regeneration loop is organized in the system.

Through the organization of the two-circuit system, most of the product gas is supplied to the consumer. There is practically no waste part of the gas in the system.

Compressed gas is supplied to the block of sorption gas drying. The work of the sorption block is based on the work of the cycle with variable pressure. At the first step of the cyclorama operation, the adsorber is filled up to the working pressure, at the second step the dry gas production stage passes, and in the third step the sorbent properties in the adsorber are restored. Simultaneously, all three adsorbers pass through different stages of the cycloramas, thus achieving a constant product flow of the dried gas of the PSA stage.

The first recycling circuit combines the sorption (PSA) and membrane stage as follows. The wet flow of PSA stage is fed to the membrane module. The non-permeated air returns to the PSA stage to regenerate the zeolite. The second circuit combines a membrane module and a condenser in which the
flow of moist air is cooled. Water vapor condenses and leaves the system, and dry gas returns to the system.

4. Conclusions

In the paper, schemes of membrane-refrigeration drying and removal of water vapor from compressed gas for use in industry are considered. A scheme of a hybrid steam separator with two recirculation circuits is proposed, consisting of three stages.

The first stage of the scheme is represented by a PSA block consisting of three adsorbers filled with a solid zeolite, which absorbs water vapor well. The second stage of the circuit is the membrane module, to which the wet flow of the PSA stage is fed, the membrane material of which the membrane module is composed, has a high water vapor permeability value. The third stage - the condenser serves to condense water vapor from the gas flow penetrated through the membrane.

The first recirculation loop combines the sorption (PSA) and membrane stage as follows. The wet flow of the PSA stage is fed to the membrane module. The non-permeated air returns to the PSA stage to regenerate the zeolite. The second circuit combines a membrane module and a condenser in which the flow of moist air is cooled. Water vapor condenses and leaves the system, and dry gas returns to the system.

Through to the proposed scheme for organizing a hybrid system, it is possible to carry out deep dehydration of the compressed gas without loss of pressure in the flow and loss of a part of the product stream that is usually returned to regenerate the sorbent in the PSA drying method.

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