RESEARCH ON THE EFFECTIVE HYDRODYNAMICS OF AN ADSORBER WITH RUBBER MEMBRANES

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Abstract

An installation for ethanol purification using membrane elements for separation of gas and liquid systems in adsorption processes is being investigated. The stability of membrane elements and the duration of their operation due to favorable hydrodynamic conditions are indicated. A mixer in the form of two circular coaxial discs of different diameters with spiral slots is proposed.

Keywords: *rubber membrane, adsorption, ethyl alcohol.*

Introductions. Adsorption refers to the process of absorbing one or more components from a gas mixture or solution by a solid substance - an adsorbent. The adsorption process is selective and reversible. Due to its reversibility, it becomes possible to extract substances absorbed by the adsorbent. Adsorption is mainly applied at low concentrations of the substance being absorbed in the feed mixture when nearly complete removal of the adsorbate is required. Adsorption processes are widely used in industries for gas purification and drying, purification and clarification of solutions, separation of gas or vapor mixtures, especially in the extraction of volatile solvents from their mixtures with air or other gases. In some cases, substances are recovered from the adsorbent after adsorption. The importance of adsorption processes has increased significantly in recent times due to the growing demand for high-purity substances. In chemisorption, a bond is formed as a result of reactions between molecules of the absorbed substance and surface molecules of the adsorbent [1].

Porous solid substances with a large specific surface area are used as adsorbents. When selecting a solid adsorbent, it is necessary to consider both the pore size of the adsorbent and the degree of activity of substance adsorption. In industry, activated carbon, mineral adsorbents, synthetic ion exchange resins, and membranes are used as adsorbents [2].

The **purpose** of the report is the operation of an adsorption unit using membrane elements (Figure 1). The main factors influencing the selection of membrane material elements include the degree of swelling while maintaining their mechanical strength, high adsorption capacity of membrane elements, thermal stability over a wide range of temperatures, as well as resistance to alkalis, acids, and polar organic solvents. These properties determine the stability of membrane elements and their service life. These requirements are met by membranes made of synthetic silicone rubber, which are cylindrical with an external diameter of 8 mm, internal diameter of 5 mm, and height of 8 mm, with an adsorption capacity of up to 2 kg of organic matter per 1 kg of membrane elements, and operate in a temperature range from 10°C to 180°C.

Materials and methods. An adsorption unit for ethanol purification is used in the food industry for the separation of gas and liquid systems in adsorption and ion exchange processes. Particularly in the production of alcohol, primarily ethanol, and products derived from it, as shown in Fig. 1. The operation of the adsorber occurs as follows: Ethyl alcohol (with a strength of 90 to 96%), containing organic impurities (aldehydes, ketones, fusel oils, etc.), is fed into chamber 1 through inlet nozzle 5. A mixer in the form of two circular coaxial discs of different diameters with spiral slots 7, which is installed between the upper and lower limiting grilles 3 using a motor with mechanical transmission 4, continuously mixes the adsorbing layer 2 of membrane elements (the number of rotations of the stirrer is from 0,5 s^{-1} to 1 s^{-1}), generating radial and tangential liquid flows, thereby creating favorable hydrodynamic conditions for contacting the membrane elements 2 with ethanol. The spiral slots on the circular coaxial discs 7 additionally induce axial movement of the membrane elements 2 in the mixture. Different diameters of the two circular coaxial discs, decreasing vertically, form flows with different linear velocities, resulting in pressure gradients in the liquid. Thus, complete mixing of the mixture in the adsorber is ensured. Therefore, radial, tangential, and axial movements of the liquid will constantly disturb the membrane elements 2, preventing the formation of stagnant zones throughout the working volume of the ethanol adsorber.

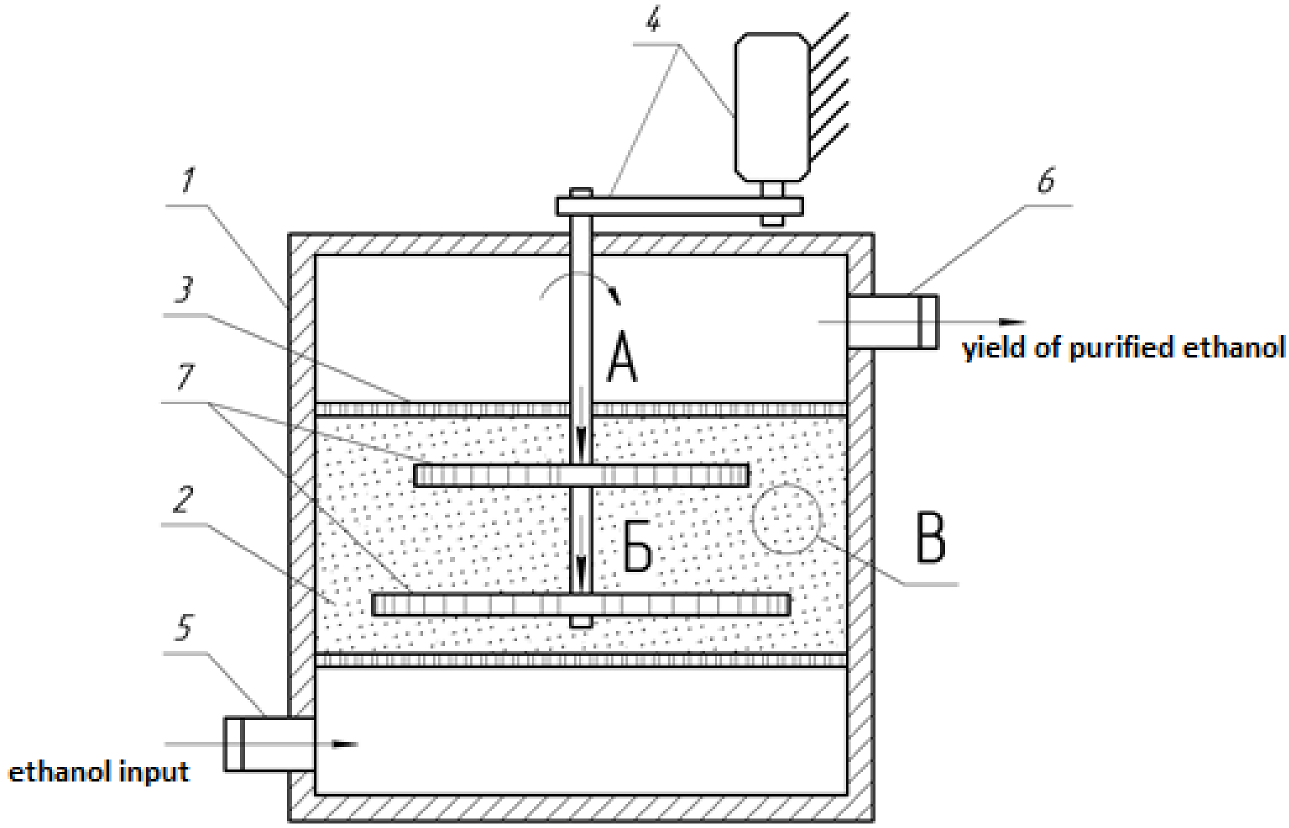

Fig. 1. Adsorption unit

The temperature of the outlet ethyl alcohol can range from 10°C to 50°C. During this process, organic impurities are actively removed from the ethyl alcohol, accumulating in the caverns (micropores) of membrane elements 2. Unlike the sorption of organic impurities by other sorbents, such as activated carbon, where the sorbent primarily captures easily sorbed substances, becomes saturated with them, and can no longer absorb heavy sorbed substances, membrane elements 2, thanks to their plasticizing effect, simultaneously remove both easily and heavily sorbed impurities from ethanol. Therefore, during sorption by membrane elements 2, we obtain ethyl alcohol containing from 10^{-4} to 10^{-5} % (ppm) of organic impurities, which is significantly below the maximum permissible concentrations. Additionally, during sorption with activated carbon, heat is released and the temperature increases, which negatively affects the sorption process. Conversely, when sorbing with membrane elements 2, increasing the temperature activates the process. The purified ethanol obtained exits the adsorber through the outlet nozzle 6 and enters the storage tank.

Results and discussion. To restore the adsorption properties of membrane elements 2 (adsorbent), their regeneration is carried out, meaning the process of removing adsorbed organic impurities from ethyl alcohol. To conduct the regeneration process, ethanol is drained from the adsorber through the inlet nozzle 6, and hot air or superheated steam (temperature ranging from 100°C to 110°C) is introduced through the same nozzle 6. This hot air or steam passes through the limiting grilles 3 and the sorbent layer 2, exiting through the outlet nozzle 7 along with the vapor phase of organic impurities. The desorption process takes approximately 30-40 minutes.

The mathematical model of the process of adsorption of organic liquid - ethanol by a polymer membrane element 2 (adsorbent), taking into account the swelling of the membrane element 2 and the conditions of the process uniqueness, can be represented as follows [3]:

$$\begin{aligned} &\frac{\partial C}{\partial \tau} = D\left(\frac{1}{r_{\text{int}}^2}\frac{\partial^2 C}{\partial \eta^2} + \frac{1}{\eta}\frac{1}{r_{\text{int}}^2}\frac{\partial^2 C}{\partial \eta^2}\right), \\ &\eta = 1 \quad \beta_1\left(C^* - C\right) = \frac{D}{r_{\text{int}}}\frac{\partial C}{\partial \eta}, \\ &\eta = K \quad \beta_2\left(C^* - C\right) = \frac{D}{r_{\text{int}}}\frac{\partial C}{\partial \eta}. \end{aligned} \tag{1}$$

The physical model of the regeneration (desorption) process is conducted as follows: Heating the membrane elements 2 activates the movement of molecules of absorbed organic impurities located in the cavities (micropores) of the walls of the membrane elements. These molecules penetrate through thin partitions separating the cavities. This process is called molecular-level thermal diffusion. After passing through these partitions, the molecules reach the outer surface of the membrane elements 2, where they come into contact with the hot gaseous heat carrier (air or superheated steam), receive heat of phase transition, transform into vapor, and detach from the surface of the membrane elements 2.

Conclusions. The process of regenerating membrane elements has certain advantages compared to the regeneration process of activated carbon. Firstly, there are no sorbent costs, whereas the costs of regenerating activated carbon amount to 25-30% due to its conversion into dust. Secondly, after a certain period of operation of the adsorber with activated carbon, it needs to be completely replaced, whereas an adsorber with membrane elements does not require such replacement. Thirdly, during the regeneration of activated carbon, its sintering may occur, while this does not happen with membrane elements. Such an adsorber for ethanol purification will provide efficient uninterrupted operation of the unit, favorable hydrodynamic conditions, high mechanical strength and adsorption capacity of membrane elements, resistance to acids, alkalis, and other inorganic and organic substances, eliminating the need for replacing activated carbon and constant cleaning of the adsorber, reducing ethanol production costs.

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