Cleaning of Atmospheric Air from Organic and Inorganic Industrial Toxicants and Microorganisms by High-Tech Functional Sorbent

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Abstract. The physicochemical and absorption properties of the new sorbent obtained by mixing finely ground 100 g of Portland cement - 500, 100 g of the molded glass of the Astrakhan region with 100 cm³ of 10% aqueous sodium chloride solution and forming granules of the required size (from 0.5 to 5 cm in diameter), the formed mass after setting and hardening is placed in running water and maintained until the water has a negative reaction to chloride ion, after drying at 80-850 °C, the granules are placed in a 40% aqueous solution of diethanolamine (DEA) for 1 h, then the granules are transferred to a sieve, wherein the excess of DEA is removed, and the granules are dried in a stream of air (fan) at 20 - 400 °C. From the physico-mechanical characteristics, the main ones are defined as follows: bulk density, water resistance, vibration wear, mechanical crush strength at T 105 ° and 300 ° C, conditional mechanical strength, abradability, grindability and particle size distribution. These indicators are interrelated and allow you to predict changes in the strength characteristics of adsorbents and sorption-filtering materials in the processes of their long-term operation. Experiments have shown that the sorbent strongly adsorbs DEA and DEA salts, which are not destroyed by water and are not diluted with acid solutions. Sorbent is used to purify atmospheric air from acidic gases and water vapor, such as hydrogen sulfide, sulfur dioxide, carbon dioxide and microorganisms. The results indicate high sorption properties of the sorbent, which allows purifying atmospheric air from acidic gases to below 0.01 MPC.

1. Introduction
Traditionally, various organic and inorganic materials are used as carriers of catalysts and sorbents for purification of atmospheric air: silica gels [1], copolymers of styrene and divinylbenzene [2], fibrous and granulated cellulose [3], polyacrylonitrile [4], etc. However, in modern practice of atmospheric air purification, preference is given to combined non-reagent technologies, which allow in one apparatus
to carry out processes of deep oxidation of organic substances, sorption of suspended particles and air purification [5].

The purpose of this work is to test a new sorbent for the purification of atmospheric air in the cabins (salons) of vehicles, in the working premises of oil and gas processing and chemical enterprises, on the territory of drilling and others [6].

As object of the study we used the obtained by mixing finely ground 100 g of Portland cement - 500, 100 g of the flasks of the Astrakhan region with 100 cm³ of a 10% aqueous solution of sodium chloride and the formation of granules, the required size (0.5 to 5 cm in diameter). After setting and hardening, they are placed in running water and kept until the water has a negative reaction to chloride ion, after drying at 80-850 ° C, the granules are placed in a 40% aqueous solution of diethanolamine (DEA) for 1 hour, further granules are transferred to a sieve, then we remove the excess of DEA, and the granules are dried in a stream of air (fan) at 20 - 400 C [7].

Sorbent is intended for purification of atmospheric air from acid gases and water vapor, such as hydrogen sulfide, sulfur dioxide, carbon dioxide. The claimed sorbent, contains a mixture of flask with Portland cement - 500, containing, in terms of oxides (mass%): CaO - 40, SiO₂ - 35, Al₂O₃ - 15 and additionally diethanolamine - 5 (mass%) and water, 5 (mass%) [8].

2. The results of testing sorbent

2.1. Physico-chemical characteristic

From the physico-mechanical characteristics, the main ones are defined as follows: bulk density, water resistance, vibration wear, mechanical crush strength at T 105 ° and 300 ° C, conditional mechanical strength, abradability, grindability and particle size distribution. These indicators are interrelated and allow you to predict changes in the strength characteristics of adsorbents and sorption-filtering materials in the processes of their long-term operation. The results of the experiments are given in Table 1 [9].

| Adsorption-structural parameters of the sorbent | | | |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Fraction | V pores on benzene, m³/kg | Sᵥ on toluene m²/kg | Average diameter of pores, nm | Density ×10⁻⁵, kg/m³ | Porosity, % |
| On water | On benzene | True | Seeming |
| 20–30 | 0,350·10⁻¹ | 300·10⁻³ | 18,5 | 14,50 | 1,98 | 0,95 | 85,0 |

| Physical and mechanical parameters of the sorbent | | | |
|--------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Bulk density, % | Vibro-wear, | Water resistance, % | Mechanical crushing strength ×10⁴, n, | AbrasionGrindabilityConditi |
| kg/m³ | Water resistance, % | kg/m² | ity, % | onal mech |
| With boiling | Without boiling | T = 105 °C | T = 300 °C |
| 20-30 | 0,95 | 98,50 | 98,90 | 130,0 | 150,0 | 0,50 | 1,80 | 25,0 |

2.2. The study of static adsorption of a number of toxicants

With the aim of studying sorption in 5 dm³ bottles using a vacuum pump, a small rarefaction was created (residual pressure ~ 0.6 × 10⁵ n / m²) and gases or vapors of the test substance were passed through a special pipe. The vapors were generated by heating a portion of the substance (acetone, acetaldehyde, alcohols, phenol) in a test tube with a vapor tube or as a result of a chemical reaction of copper with sulfuric or nitric acid (respectively, SO₂ or NO₂ gases were obtained) [10]. Next, air was
passed into the bottle until a total pressure of $1.02 \times 10^5 \text{ n/m}^2$ was reached, and a mixture of air and test gas from the bottle was passed through the tube with the sorbent, creating a rarefaction at the outlet of this tube. The whole system was thermostatically controlled, for this purpose it was washed by air with a temperature of $278 \pm 5, 295 \pm 2, 320 \pm 2 \text{ K}$ [11].

As a result of studying the sorption of acid gases on the sorbent CB-DA, the limiting capacity of the sorbent ($G_\infty$) was calculated, which turned out to be the following (Table 2).

Table 2. The limiting capacity of the sorbent ($G_\infty$).

| Substance     | G, mg/g (gram of substance per gram of sorbent) |
|---------------|-----------------------------------------------|
| H$_2$S        | 100                                           |
| CO$_2$        | 120                                           |
| SO$_2$        | 140                                           |
| H$_2$O        | 600                                           |
| NO$_2$        | 120                                           |

Experiments have shown that the sorbent strongly adsorbs DEA and DEA salts, which are not destroyed by water and are not diluted with acid solutions [12].

2.3. Diffusion of gases and water vapor into the sorbent

The enthalpy of formation or destruction of the ionic associate can be calculated using two or more diffusion coefficients for different temperatures. In the simplest case, this value $\Delta H$ can be calculated by the equation [13]:

$$\Delta H_{\text{diff}} = \frac{R \cdot T_1 \cdot T_2 \cdot \ln \frac{D_2}{D_1}}{T_2 - T_1}$$

More correct are the results obtained by $\Delta H$ from graphical calculations. In our case, as a result of studying the diffusion at temperatures of 278, 298 and 320 K, the diffusion coefficients $D_{278}, 298, 320 \text{ m}^2/\text{s}$ were found. The dependence diagram of $\ln D f (1/T \cdot 10^3)$ was constructed [14].

![Figure 1. Dependence $\ln D f (1/T \cdot 10^3)$.

...](attachment:figure1.png)
Dependence \( \ln D f (1 / T \cdot 10^3) \) is a straight line for which the slope is \( \tan \phi \). Then \( \Delta H - R m \tan \phi \), where \( R \) is the universal gas constant (\( R = 8.313 \text{ J mole}^{-1} \text{ K}^{-1} \)), \( m \) is the ratio of the scales (\( m = 1000 \) in all experiments). The results of graphic calculations of \( \Delta H \) values are presented in Table 3.

It has been established that in flasks and also in parts of plants containing silicon dioxide, the latter is in the form of clusters representing associations of three, four, six molecules of silicon dioxide. These clusters are organized in such a way that the oxygen atoms of the silanol and siloxane groups are directed to each other in the cluster [15].

### Table 3. The coefficients of molecular diffusion of gases in the sorbent.

| Substance | Temperature, K | -\( \Delta H \) kJ/mole |
|-----------|----------------|------------------------|
|           | 278            | 298                    | 320        |
|           | \( D \cdot 10^2 \) | \( \ln D \) | \( D \cdot 10^2 \) | \( \ln D \) | \( D \cdot 10^2 \) | \( \ln D \) |
| \( \text{H}_2\text{S} \) | 4,0 | -3,21 | 6,2 | -2,78 | 8,0 | -2,52 | 151,3 |
| \( \text{CO}_2 \) | 2,0 | -3,91 | 3,3 | -3,41 | 4,0 | -3,22 | 75,65 |
| \( \text{SO}_2 \) | 1,0 | -4,6 | 1,8 | -4,0 | 2,0 | -3,3 | 75,65 |
| \( \text{H}_2\text{O} \) | 6,0 | -2,81 | 8,5 | -2,47 | 13,0 | -2,12 | 50,43 |
| \( \text{NO}_2 \) | 3,0 | -3,50 | 4,3 | -3,14 | 6,0 | -2,81 | 37,82 |

Considering that the oxygen atoms of the silanol and siloxane groups contain electron pairs (\( n \)-electrons), they are easily coordinated with ions representing protonated nitrogen failure, thus forming stable compounds that do not break down when the aqueous solutions are heated to 700 °C. On the other hand, ionic associates of \( \text{H}_2\text{S} \), \( \text{SO}_2 \), \( \text{CO}_2 \), \( \text{NO}_2 \) with diethanolamine adsorptive on silica gel are also stable [16].

2.4. Water treatment results

Sorbent is an environmentally safe and effective sorbent of industrial acid gases or the same gases that can be accumulated in any way on the working sites of industrial enterprises (for example, the oil and gas complex), as well as in various enclosed spaces [17].

Table 4 shows the results of experiments on purification of atmospheric air, in which certain toxicants were introduced [18, 19].

The degree of purification \( S \) was calculated according to the formula \( S (\%) \), where \( m_{\text{mix}} \) is the content of \( \text{H}_2\text{S} \), \( \text{SO}_2 \), or \( \text{CO}_2 \) in air before purification, mg / m\(^3\), \( m_{\text{con}} \) - content of \( \text{H}_2\text{S} \), \( \text{SO}_2 \), or \( \text{CO}_2 \) in air after purification, mg / m\(^3\).

### Table 4. The results of sorption purification of atmospheric air from a mixture of hydrogen sulfide, carbon dioxide and sulfur. Comparative characteristics of atmospheric air dissemination by natural microflora without using (control) and using the declared sorbent (contact time - 5s).

| The concentration of the substance before treatment, mg / m\(^3\), the air contains a mixture of substances, the concentration of each is indicated by numbers | Cleaning results |
|---|---|---|
| Found, \( m_{\text{con}} \) mg/m\(^3\) | \( S \), % |
| \( \text{SO}_2 \) – 20,0 | 0.002 ± 0.0002 | 99,99 |
| \( \text{CO}_2 \) – 20,0 | 0.002 ± 0.0002 | 99,99 |
| \( \text{H}_2\text{S} \) – 10,0 | 0.001 ± 0.0001 | 99,99 |
Table 5. The results of sorption purification of atmospheric air from a mixture of hydrogen sulfide, carbon dioxide and sulfur. Comparative characteristics of atmospheric air dissemination by natural microflora without using (control) and using the declared sorbent (contact time - 5s).

| The object of study is | Relative humidity, % | The number of colonies of natural microflora in a Petri dish. |
|-----------------------|----------------------|---------------------------------------------------------------|
|                        | before the experiments | after the experiments |
| Box 1 (control)        | 80,0 ± 2,0            | 56,0 ± 5,0          |
| Box 2 (using sorbent)  | 80,0 ± 2,0            | 4,0 ±1,0            |

3. Conclusions
1. The tested filtering material - sorbent - according to the indicators of "abrasion" and "conditional mechanical strength" is suitable for use as a load in fast filters for cleaning atmospheric air or water;
2. The sorbent in the form of large particles has a large specific surface area, which makes it possible to apply it to trapping toxicants from water and air, while the sorption characteristics of the sorbent are maintained at a high level.
3. It is shown that the sorbent can be used to purify atmospheric air from acid gases and pathogens.

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