Preparation of catalytically active membranes containing vanadium oxides layers based on colloidal-chemical principles

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Relevance of the Research Topic

In the modern scientific context, there is growing interest in the development of hybrid technologies that integrate separation and catalytic processes. These innovative methods play a key role in optimizing production cycles, enabling the simultaneous implementation of two stages to improve efficiency and intensify chemical reactions. Such approaches have the potential to significantly transform existing methods for developing sustainable and cost-effective production processes, particularly in resource separation and purification, as well as in the treatment of exhaust gases and wastewater. One such hybrid technology combines microfiltration for the removal of coarse impurities with catalytic purification of residual dissolved organic compounds.

Development of catalytically active membranes, including those based on vanadium oxides, is a significant area of research in this field. However, successful implementation of these technologies requires a thorough understanding of the colloidal chemistry underlying their fabrication processes. Currently, there is a lack of systematic data on the influence of the conditions under which vanadium oxide-based functional layers are applied to the surface of ceramic tubular membranes using the sol-gel method on the properties of the resulting layers. Therefore, ongoing work aimed at expanding the knowledge base on the correlation between sol synthesis conditions, application parameters, and the properties of the applied layers, as well as developing methods for their preparation, represents an important scientific challenge.

Investigating the colloidal chemical aspects of the formation of catalytically active membranes could open up new horizons for their application in various fields, ranging from wastewater treatment to the synthesis of valuable chemical compounds. This could also lead to significant environmental and economic benefits, facilitating the development of cleaner and more efficient technological processes. Thus, research in this area represents a significant contribution to both scientific and practical applications, highlighting the potential for further research in this field.

The aim of this work is to develop colloid-chemical principles for obtaining functional vanadium-containing layers on the surface of ceramic tubular membranes using the sol-gel method.

Research Tasks:

1. Develop the key stages of V_2O_5 sol synthesis and obtain a set of data on its key colloidal chemical properties;

2. Select deposition methods and conditions that will produce a deposited layer with high adhesion to the substrate;

3. Develop the key stages of the membrane production process, including drying and heat treatment, and determine the effect of these conditions on the key characteristics of the deposited layers;

4. Evaluate the catalytic activity of the resulting V_2O_5/Al_2O_3 ceramic membranes in the catalytic decomposition of methylene blue and Rhodamine B dyes in dilute aqueous solutions.

Scientific novelty of the work:

1. The effect of synthesis conditions on the colloidal-chemical properties of $V_2O_5.nH_2O$ sols obtained by thermolysis of coarsely dispersed V_2O_5 in the presence of hydrogen peroxide was studied for the first time. This allowed us to identify the V_2O_5 concentration range (0.3-1.6% by weight) in which the formation of aggregation-stable sols is possible.

2. For the first time, a set of data was obtained on the colloidal-chemical properties of sols synthesized with different initial V_2O_5 concentrations (the concentration of vanadium compounds in undissolved and dissolved forms, the size, shape, and chemical composition of the particles, the viscosity of the sols, the sign and magnitude of the electrokinetic potential, the effect of the pH of the dispersion medium and the content of the indifferent electrolyte on the aggregation stability), which made it possible to select the conditions for the formation of the deposited layers.

3. For the first time, a set of data was obtained on the phase composition, specific surface area, and porous characteristics of xerogels and deposited $V_2O_5.1,6H_2O$ layers, as well as their thermal decomposition products, which made it possible to select the heat treatment regime for the deposited layers.

4. For the first time, data were obtained on the catalytic activity of V_2O_5/Al_2O_3 membranes in the decomposition reaction of methylene blue and rhodamine B, in the presence of hydrogen peroxide under visible light (without additional UV radiation).

Theoretical and Practical Significance

1. Colloid-chemical principles for producing catalytic membranes with a deposited V_2O_5 layer have been developed using sols obtained by hydrolysis of coarsely dispersed V_2O_5 in the presence of hydrogen peroxide at boiling point. The relationship between the sol synthesis

conditions, its colloid-chemical properties, and their influence on the deposition stage conditions has been demonstrated.
2. A method for depositing layers analogous to the filtration method has been implemented—a method that does not require complex instrumentation and is scalable. This method enables the deposition of V_2O_5/Al_2O_3 membrane layers in a single step and the adhesion of the layers to the surface in a single drying and heat treatment cycle.
3. The main stages of depositing V_2O_5/Al_2O_3 membrane layers using synthesized sols with a deposited layer specific gravity of up to 9 mg/cm2 have been developed. Optimal heat treatment conditions (650°C) for achieving good adhesion to the surface of α-Al_2O_3-based membranes were determined. The pH range of solutions in which deposited layers obtained at different heat treatment temperatures retain chemical stability was determined.
4. Catalytic activity in the decomposition of the organic dyes methylene blue and Rhodamine B in dilute aqueous solutions in the presence of hydrogen peroxide under visible light (without additional UV radiation) was established. This activity exceeds the catalytic activity of powdered catalysts based on $V_2O_5$by an order of magnitude.

Thesis to be defended:

1. The main stages of the synthesis of $V_2O_5.nH_2O$ sols by thermolysis of coarsely dispersed V_2O_5 in the presence of hydrogen peroxide and the conditions under which they are carried out, enabling the formation of aggregation-stable sols.
2. A set of data on the colloidal-chemical properties of sols synthesized with different initial V_2O_5 concentrations, confirming the possibility of controlling the colloidal-chemical properties of sols during the synthesis stage. Data on the range of dispersion medium pH values and supporting electrolyte content at which the sols retain their aggregation stability.
3. A set of data on the phase composition, specific surface area, porous characteristics of $V_2O_5.1{,}6H_2O$ xerogels, and the products of their thermal decomposition.
4. A method for depositing layers analogous to the filtration method. This method enables the deposition of V_2O_5/Al_2O_3 membrane layers in a single step and the fixation of the layers on the surface in a single drying and heat treatment cycle.
5. Conditions for producing V_2O_5/Al_2O_3 catalytic membranes with a specific mass of the applied layer up to 9 mg/cm2, under which the layer exhibits satisfactory adhesion to the substrate.
6. V_2O_5/Al_2O_3 ceramic membranes exhibit catalytic activity in the decomposition of the organic dyes methylene blue and Rhodamine B in dilute aqueous solutions in the presence of hydrogen peroxide under visible light (without additional UV radiation).