Calculation of an electrochemical reactor for cleaning the air of the city from hydrogen sulfide emissions

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Abstract. The environmental safety of the urban economy requires the creation of new environmentally friendly technologies that ensure human protection from the negative impact of water management systems, in particular the urban sewer system, which is a potentially dangerous source of decomposition products of biological waste. Hydrogen sulfide is a gas that has a significant danger for both the city population and the high corrosivity of metal and concrete structures. At the Department of General and Applied Chemistry (VSTU), we developed an electrochemical method for purifying air from hydrogen sulfide, which allows to neutralize it locally, in the zone of hydrogen sulfide emission, with the release of environmentally friendly products: chemically pure sulfur and water.

1. Introduction

To clean industrial gases from the presence of hydrogen sulfide, liquid adsorption methods are very often used [1], which absorb hydrogen sulfide from a mixture of gases and then desorbed with its subsequent burning. As a result, another environmentally hazardous sulfur dioxide is released into the atmosphere.

The development of modern environmentally friendly methods is an urgent technological problem. Based on the analysis of the environmental friendliness of the methods, it is concluded that the electrochemical method is most suitable [2].

2. Method

In order to study the technological solution of the electrochemical oxidation of hydrogen sulfide, based on previously studied electrochemical parameters of the process of anodic oxidation of hydrogen sulfide. In laboratory conditions, in an experimental setup [3], air containing hydrogen sulfide was blown through the tube at a speed \( V = 1 \text{ cm/s} \). Let us accept the condition that the rate of the electrochemical reaction does not depend on the concentration of hydrogen sulfide in the air (sewer collectors) and will be constant at \( 20V_{0.1} = 1.4 \text{ mg/m}^3 \text{h} \) (1), According to [4], this is a zero order reaction for the reaction product.

\[
V_{0.1} = \frac{dc}{d\tau} = \text{const}
\]  

In this case, for the zero-order reaction in the specific displacement reaction, we obtain from the equation (2)
\[ \tau = \frac{C_0 - C_k}{V_{\text{in}}} \]  \hspace{1cm} (2)

I.e. the residence time of the reaction mass - the air - is determined by the initial and final concentration of hydrogen sulfide in the air while the latter should be equal to or less MPC_{H_2S}C_k - 0.008 \text{ mg/m}^3. \text{[4].}

Let us recalculate the reaction rate for sulfur (1) to the reaction rate for hydrogen sulfide:

\[ V_{\text{in,S}} = V_q \left(\frac{M_{H_2S}}{M_S}\right) = 1.4 \frac{34}{32} = 1.5 \text{ mg/m}^3h \]  \hspace{1cm} (3)

The initial concentration of hydrogen sulfide in the air is taken \( C_0 = 0.2 \text{ mg/m}^3 \), i.e. 50 times less than allowed in the work area \( C_{\text{w,a}} = 10 \text{ mg/m}^3 \)[4].

From equation 4 we obtain the residence time in the electrochemical reactor, providing the necessary degree of air purification

\[ \tau = \frac{0.2 - 0.008}{1.5} = 0.135h \]  \hspace{1cm} (4)

If the productivity is \( q_e = 1 \text{ m}^3/h \) for cleaned air, then the cross-sectional area is determined from the continuity equation:

\[ S = \frac{q_e}{\omega} = \frac{1}{0.01 \cdot 3600} = 0.0278 \text{ m}^2 \]  \hspace{1cm} (5)

and the diameter of the industrial module:

\[ d_i = \sqrt{\frac{4S}{\pi}} = \sqrt{\frac{0.0278}{3.14}} = 0.188 \text{ m} \]  \hspace{1cm} (6)

The volume of the module for a capacity of \( 1 \text{ m}^3/h \) hour will be:

\[ V = q_e \cdot \tau = 1 \cdot 0.135 = 0.135 \text{ m}^3. \]  \hspace{1cm} (7)

Hence, the length of the tubular reactor (module) will be:

\[ l = \frac{V}{S} = \frac{0.135}{0.0278} = 4.85 \text{ m} \]  \hspace{1cm} (8)

Thus, in an electrochemical reactor for producing sulfur from hydrogen sulfide (located in the city’s sewer systems) in air at an industrial module capacity \( q_e = 1 \text{ m}^3/h \) and hydrogen sulfide concentrations: initial \( C_0 = 0.2 \text{ mg/m}^3 \) and finite \( C_k = 0.008 \text{ mg/m}^3 \) (MPC), air velocity in the pipe \( \omega = 1 \text{ cm/s} \) need in tube reactor with a volume of \( V = 135 \text{ l} \) with an inner diameter of the pipe \( d_i = 0.188 \text{ m} \) and length \( l = 4.85 \text{ m} \).

The residence time of the cleaned air in the reactor is \( \tau = 0.135h \) at a reaction rate of hydrogen sulfide \( 1.5 \text{ mg/m}^3h \). We determine the Reynolds number to determine the flow:

\[ \text{Re} = \frac{\omega d_i \rho}{\eta} = \frac{0.01 \cdot 0.188 \cdot 1.2}{1.9 \cdot 10^{-5}} = 120 \]  \hspace{1cm} (9)

Which allows us to conclude that the flow regime is laminar.

If productivity increases 10 times, i.e. \( q_e = 10 \text{ m}^3/h \), then the cross-sectional area (5) \( S = 0.278 \text{ m}^2 \), and diameter (6) \( d_i = 0.594 \text{ m} \), volume will become \( V = 1.35 \text{ m}^3 \) and length (8) \( l = 4.85 \text{ m} \). In this case, the Reynolds number is \( \text{Re} = 379 \), i.e., the flow regime remains laminar.

At productivity 100 \text{ m}^3/h the cross-sectional area (5) \( S = 2.78 \text{ m}^2 \), reactor pipe inner diameter (6) \( d_i = 1.88 \text{ m} \), this is already a column with the same length (8) \( l = 4.85 \text{ m} \). Reynolds number will be \( \text{Re} = 1200 \) - laminar mode. electrochemical reactor scheme is shown in Figure 1.
Figure 1. Electrochemical reactor scheme: $C_0$ – concentration $H_2S$ at the inlet, $C_k$ – concentration at the outlet $H_2S$.

Further tenfold increase in productivity $q_v$ up to 1000 m$^3$/h is impractical, since the diameter of the column $d_i = 5.94$ m and will become longer than the length $l = 4.85$.

3. Summary
The above calculations, taking into account the parameters of the electrochemical process of oxidation of hydrogen sulfide [5]: current density $0.8$ A/dm$^2$, voltage $2.5$ V, allow us to navigate during the design of a real installation for cleaning sewer air from hydrogen sulfide in emission zones.

Reference
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