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IMPROVING THE EFFICIENCY OF AIR PURIFICATION FROM HYDROGEN SULFIDE BY THE ABSORPTION-ELECTROCHEMICAL METHOD THROUGH THE MODERNIZATION OF THE MASS TRANSFER APPARATUS

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Abstract. *The paper presents the results of an experimental study of the efficiency of air purification from hydrogen sulfide using a modernized design of a two-stage mass transfer apparatus as part of an absorption-electrochemical setup. An approach to intensifying mass transfer by optimizing the apparatus design and increasing the number of stages of absorbent dispersion is proposed. Experimental studies of hydrogen sulfide removal from air in a closed circulation loop were carried out under different operating modes of single-stage and two-stage mass transfer apparatuses. The results show that the use of a two-stage mass transfer apparatus provides a higher specific efficiency of hydrogen sulfide removal per unit of absorbent consumption, which makes it possible to use the sorbent more rationally and reduce the operating costs of purification systems. The obtained data can be used in the design of mass transfer apparatuses as well as in further research on the modernization of their designs and optimization of operating modes.*

Key words: *mass transfer apparatus, hydrogen sulfide, absorption-electrochemical method, mass transfer, removal of toxic gases.*

Introduction.

Air pollution by harmful gases is one of the most urgent environmental problems today, directly affecting the quality of human life and the state of natural ecosystems. The constantly growing volumes of industrial production lead to an increase in emissions of toxic compounds, which intensify negative processes in the atmosphere, soils and water bodies, creating global threats to the environment and human health.

One of the most common and dangerous atmospheric pollutants is hydrogen sulfide. This gas has a characteristic rotten egg odor and enters the atmosphere both from natural sources (volcanic activity, decomposition of organic matter under anaerobic conditions) and as a result of anthropogenic activities.

Air purification from hydrogen sulfide is a critically important problem for a number of industrial sectors such as the food, chemical and oil and gas industries, metallurgy, pulp and paper production, as well as for cities and settlements where the main sources of pollution are wastewater treatment plants [1], solid waste landfills and drainage systems.

The absorption-electrochemical purification method shows promising results in terms of economic and energy efficiency compared to traditional absorption processes [2]. However, achieving modern regulations [3] and standards governing the maximum permissible hydrogen sulfide concentrations in emissions requires further modernization of purification equipment and detailed experimental studies of its efficiency under various operating modes.

Purpose of the study.

The main purpose of the study is to increase the efficiency and productivity of the process of contaminated air purification from hydrogen sulfide by modernizing the design of the mass transfer apparatus from a single-stage to a two-stage scheme, taking into account the principles of absorption-electrochemical treatment and experimental verification of the developed solutions.

Main text.

The study is based on the analysis of experiments performed in previous works on hydrogen sulfide removal from air in a closed circulation loop of a gas mixture. It was found that in the absence of absorption treatment, only due to natural oxidation of hydrogen sulfide during multiple circulation in the loop, the degree of its removal is about 15…25% over 30 minutes of setup operation [2], with the experiments performed at a relative air humidity above 95%.

In a subsequent series of experiments, the efficiency of air purification from hydrogen sulfide was studied under conditions of its circulation in a closed loop with spraying of a liquid absorbent in a single-stage mass transfer apparatus [4], where an increase in the degree of removal up to approximately 25…55% was obtained depending on the process parameters.

Given the insufficient efficiency of the single-stage scheme to meet current

environmental standards, a two-stage mass transfer apparatus with multiple dispersion of the liquid absorbent was designed and patented. Its design is aimed at intensifying mass transfer between the gas and liquid phases [5]. The schematic of this mass transfer apparatus is shown in Figure. 1.

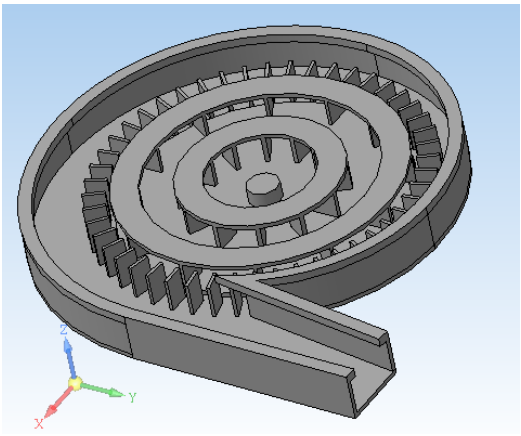

Figure 1 – 3D model of the two-stage mass transfer apparatus

From a chemical point of view, the efficiency of absorption purification of gas flows from hydrogen sulfide is primarily determined by the rate of the corresponding chemical reactions between H_2S and the components of the absorbing solution. The reaction rate is described by the kinetic equation:

$$v = k \cdot c_{H2S}^{n} \cdot c_{reag}, \quad (1)$$

where k is the reaction rate constant, c_{H2S} and c_{reag} are the concentrations of the reactants in the liquid phase, and n is the reaction order. The constant k is a fundamental characteristic of the reaction and depends mainly on temperature, the nature of the reacting substances and the presence of a catalyst, but not on the apparatus design as such.

Within the absorption-electrochemical method for gas–liquid systems, such as hydrogen sulfide absorption, the actual absorption rate is determined not only by the intrinsic reaction kinetics but also by the intensity of mass transfer from the gas phase into the liquid. Therefore, the real rate of the purification process is reasonably expressed as the product of the kinetic term k and the mass transfer characteristics of the apparatus, namely the mass transfer coefficient and the effective interfacial contact area. In a simplified form, the volumetric rate of the process can be written as

$$r \sim k \cdot a \cdot c_{H2S}, \quad (2)$$

where a is the specific interfacial area and c_{H2S} is the hydrogen sulfide concentration in the liquid at the phase boundary. Thus, even at a constant reaction rate constant, an increase in contact area and intensification of mass transfer directly lead to an increase in the overall absorption rate.

There are two fundamentally different but complementary approaches to increasing purification efficiency: increasing the reaction rate constant k by using catalysts or optimizing the composition and temperature of the absorbing solution, and intensifying mass transfer by improving the design of the mass transfer apparatus. In industrial conditions, the possibilities of influencing k are often limited by requirements for sorbent stability and cost, equipment corrosion resistance and operational safety. In contrast, modernization of the apparatus (transition from a single-stage to a two-stage scheme) makes it possible to significantly increase the effective interfacial surface by optimizing hydrodynamics, equalizing velocity fields, reducing stagnant zones and improving the delivery of H_2S to the reaction zone without changing the chemical nature of the process.

The experiments were carried out in the Heat and Mass Transfer Laboratory of Admiral Makarov National University of Shipbuilding. The schematic of the experimental setup for studying hydrogen sulfide removal efficiency is shown in Figure. 2.

During the experiments, the air temperature varied in the range of 18…21 °C, the liquid temperature in the range of 12…16 °C, and the specific sorbent flow rate from 0.036 to 0.096 g/kg.

To compare the study results, the following dependence was used to evaluate the purification degree:

$$\eta(t) = \frac{c_0 - c_f(t)}{c_0} \cdot 100\%, \quad (3)$$

where c_o is the initial H_2S concentration, mg/m^3, and c_f is the final concentration, mg/m^3.

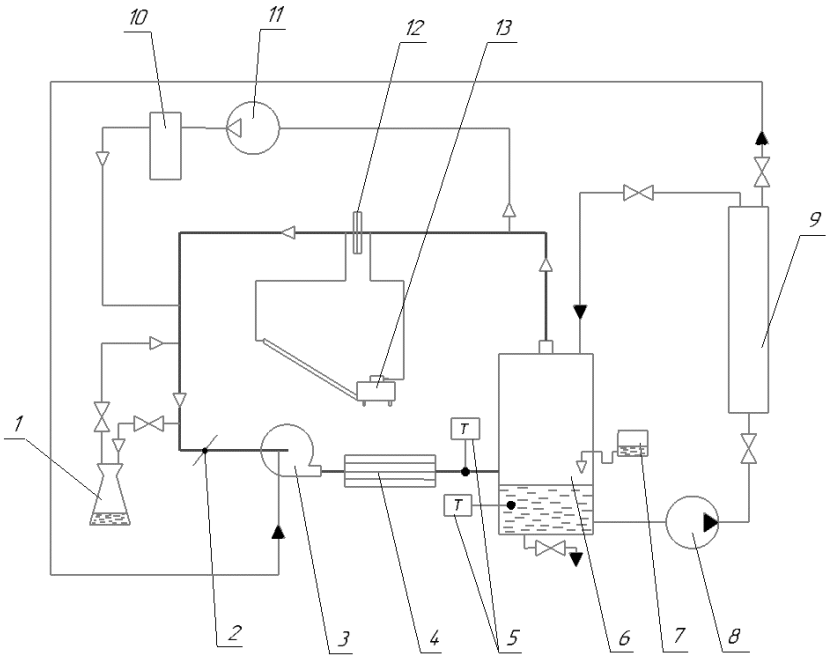

Figure 2 – Schematic of the experimental setup for studying the efficiency of hydrogen sulfide removal from air by the absorption-electrochemical method:

1 – vessel for H_2S generation; 2 – throttle valve; 3 – mass transfer apparatus; 4 – separation device; 5 – digital thermometer-hygrometer TPM 20; 6 – storage tank; 7 – make up tank with hydraulic seal; 8 – pump; 9 – electrochemical reactor; 10 – compressor; 11 – ISS gas analyzer; 12 – orifice plate; 13 – micromanometer

For the obtained results, an additional indicator of specific hydrogen sulfide removal efficiency per unit of absorbent consumption was used:

$$E = \frac{\eta}{Q_s}, \quad (4)$$

where η is the hydrogen sulfide removal efficiency, and Q_s is the specific absorbent flow rate, g/kg. This indicator makes it possible to adequately compare the performance of the apparatuses at different absorbent flow rates and to justify the economic feasibility of using various designs.

Experimental results.

The results of the experimental study of hydrogen sulfide removal from air by the absorption-electrochemical method using single-stage and two stage mass transfer apparatuses are presented in Table 1.

Table 1 – Operating indicators of the hydrogen sulfide removal setup using the absorption-electrochemical method

Experiment №	Initial H_2S concentration c_o, mg/m^3	Final H_2S concentration c_f, mg/m^3	Specific absorbent flow Q_s, g/kg	Efficiency η, %	Specific efficiency, E, %·kg/g
Single-stage mass transfer apparatus					
1	45	35	0,036	22,2	617
2	96	66	0,048	31,2	650
3	61	37	0,06	39,3	655
4	47	23	0,072	51	708
5	82	38	0,079	53,6	679
6	69	38	0,096	55,1	573
Two-stage mass transfer apparatus					
1	87	59	0,036	32,2	894
2	57	31	0,048	45,6	950
3	56	28	0,06	50	833
4	103	39	0,067	62,1	928
5	100	27	0,079	73	924
6	78	16	0,096	79,5	828

Analysis of the obtained data indicates a significant difference in the efficiency of the two apparatus designs. The two-stage mass transfer apparatus provided considerably higher hydrogen sulfide removal at all investigated absorbent flow rates compared to the single-stage scheme.

For the single-stage apparatus, the specific hydrogen sulfide removal efficiency per unit absorbent flow ranged from 573 to 708%·kg/g, with a maximum at an absorbent flow rate of 0.072 g/kg. For the two-stage apparatus, this indicator was significantly higher, from 828 to 950%·kg/g, demonstrating more rational sorbent use over a wide range of operating conditions. Detailed analysis of Table 1 shows that the two-stage mass transfer apparatus provides approximately 1.27…1.49 times higher specific hydrogen sulfide removal efficiency per unit absorbent flow compared to the single-stage scheme.

Mass transfer apparatuses operate most efficiently in droplet flow regime rather than in jet regime [6]. The use of a two-stage configuration with multiple liquid dispersion allows the unit to operate efficiently in a wider range of absorbent flow rates

while maintaining a favorable droplet regime throughout the entire operating range. An increase in removal efficiency from 55% for the single-stage design to 79.5% for the two stage one at similar absorbent flow 0.096 g/kg) confirms the effectiveness of the proposed design solution. This increase is achieved due to an enlarged interfacial contact area resulting from more dispersion stages, optimized apparatus hydrodynamics, reduced stagnant zones and improved reactant transport to the active reaction zone.

Summary and conclusions.

The problem of increasing the efficiency of air purification from hydrogen sulfide by the absorption-electrochemical method through modernization of the mass transfer apparatus from a single-stage to a two-stage design with multiple absorbent dispersion has been considered. Experimental data obtained in research showing that the two-stage mass transfer apparatus provides a hydrogen sulfide removal degree of 32.2…79.5% at a specific absorbent flow rate of 0.036…0.096 g/kg, which is 1.27…1.49 times higher than for the single-stage apparatus. The specific hydrogen sulfide removal efficiency per unit absorbent consumption increased from 573…708 %·kg/g to 828…950 %·kg/g.

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