Absorption cleaning of ventilation emissions

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Abstract. Various methods are used to clean industrial ventilation emissions: mechanical, electrical, absorption, thermal, catalytic. Absorption methods are economically justified when the concentration of impurities in the gas stream is more than 1 %, which are present in the vent emissions of technological industries. The main element of the absorption cleaning systems is the absorber, the design and technological parameters of which determine the entire layout of the gas cleaning system. For the proper selection and calculation of the absorption treatment scheme, it is necessary to know the production technology, equipment, where emissions are generated in excess of the norms of maximum permissible concentration, as well as the properties of process flows. Using the universal modeling program ChemCad allows reducing the time for calculating the thermodynamic and physicochemical properties of flows, increase their accuracy and eliminate errors when choosing treatment equipment at industrial enterprises. The results of the study were proposed when designing a scheme for the absorption cleaning of ventilation emissions in the production technology of paint and varnish products or the technology of production of drywall.

Key words: absorption, cleaning, ventilation, emission, properties, hydrogen sulfide.

1 Introduction

Observations of the state of atmospheric air pollution in the territory are carried out throughout the territory of the Russian Federation. Sampling of atmospheric air at stationary observation posts is carried out according to the full program – daily four times a day, at automatic stations (on the main impurities) – every 20 minutes. Concentrations of suspended substances, sulfur dioxide, nitrogen dioxide, carbon monoxide, nitrogen oxide, phenol, formaldehyde, ammonia, hydrogen sulfide, sulfuric acid aerosols, benzene, toluene, ethylbenzene, xylene, acetone, chloroform, carbon tetrachloride, chlorobenzene, heavy metals are determined in air samples at stationary posts.

At automatic posts in many cities of the Russian Federation, atmospheric air is analyzed for the content of carbon monoxide, sulfur oxide, nitrogen oxide and dioxide, hydrogen sulfide, ozone. Methods of ventilation emissions cleaning are known, and the choice of a specific option depends on a variety of parameters, such as the initial concentration of the pollutant, the required degree of purification, the physical and chemical composition of the gas mixture, the temperature, the amount of flow, etc. [1–9].

Absorption is an effective method of cleaning gas emissions in many processes and may be recommended for painting or gypsum board technology. At the same time, most of the compounds contained in gas emissions can be recycled and used as raw materials for this technology or for other industries[10–17].

The absorber functions according to certain laws. The saturated absorbent is regenerated in the column and the regenerated absorbent is returned to the absorber. Consequently, gas purification takes...
place in equipment interconnected by material and heat flows and in which a certain sequence of technological operations is carried out. Therefore, based on the definition [18–22], it can be concluded that the process of cleaning ventilation emissions by absorption allows considering it as a chemical-technological system, which allows to calculate this system using universal modeling programs.

Process calculations of the main process equipment for cleaning ventilation emissions are optimally carried out using universal modeling programs, which contain a very developed database for describing flow parameters [23], [24]. There are technical solutions for stabilization of operation for exhaust ventilation system [25–27]. This makes it possible to carry out multivariate calculations without significant material and time costs. However, these programs are oriented towards modeling chemical and technological processes and do not always take into account some aspects arising in the design of ventilation systems. For successful calculation, the main modules of the universal modeling programs must be adjusted accordingly, which allows functional use of modern ChemCad.

2 Materials and methods

2.1 Absorption Method of Cleaning of Ventilation Emissions

The article calculated the absorber of the gas cleaning system with the use of universal modeling programs ChemCad. Figure 1 shows the synthesized design diagram.

The absorbent (stream 1) is fed to the top of the absorber and the gas to be purified consisting of hydrocarbons and air (stream 2) is fed to the bottom. On the contact devices installed in the absorber, a mass exchange process takes place, whereby hydrocarbons are dissolved in the absorbent, which is saturated and withdrawn from the absorber (stream 4) from the bottom. The purified gas is withdrawn from the top (stream 3).

The main task of computer simulation of the process was to determine the composition and flow rate of gases leaving the absorber. For column calculation in the program database, there are different modules of absorption columns, which differ from each other by the laid-down mathematical description. Based on the recommendations of the program, for calculation of a column the TOWR module (module 1) was used. To converge the calculation, enter the following data in the module specification: column pressure, differential pressure, number of theoretical trays, capacitor and cube operation modes.

![Diagram of absorber](image)

Figure 1. The design diagram of the absorber of the gas cleaning system synthesized with the use of ChemCad.

The pressure in the column was set based on production data. Since the capabilities of the module allow entering parameters of contact devices, and in the database, the geometric and mass exchange characteristics of different nozzles are presented, in the module the type of nozzle was specified, and
efficiency and pressure difference in the column were calculated by the program. Since there is no reflux and evaporator in the flow chart, their parameters were not specified in the module specification.

2.2 Cleaning of Ventilation Emissions from Hydrogen Sulfide

Problem definition. In the area of the local gypsum plant in megalopolis, there is an excess of hydrogen sulfide in MPC emissions by about 20 times. The mass concentration of a substance such as hydrogen sulfide can be determined by photometry from the reaction of finding the methylene blue component in atmospheric air in a single operation. Measurement range of mass concentration of hydrogen sulfide from 0.006 to 0.1 mg/m³ with air sample volume of 80 dm³ is considered.

Hydrogen sulfide is toxic and explosive, negatively affects the environmental situation of the adjacent area, and in large concentrations in the room emits many metals and insulation of wires. Therefore, the introduction of hydrogen sulfide purification equipment in exhaust ventilation systems is relevant.

The work deals with the process of cleaning the ventilation emissions from H₂S with 45 % aqueous solution of N-methyldiethanolamine (MDEA) with the content of hydrogen sulfide in the regenerated absorbent of 0.22 %.

Basic data. A hydrogen sulfide-containing gas with a temperature of up to 30°C and a pressure of 0.1–0.17 MPa enters the lower part of the absorber, into the upper part of which 45 % regenerated water solution of MDEA with a temperature of up to 40°C is supplied. The purified gas is removed from the top of the absorber for further processing. The saturated MDEA solution from the bottom of the absorber is fed to the desorption column for regeneration.

The absorption of hydrogen sulfide in the absorber follows the following stoichiometric equations:

\[
2RNH_2 + H_2S \rightarrow (RNH_3)_2S, \quad (1)
\]

\[
(RNH_3)_2S + H_2S \rightarrow 2RNH_3HS. \quad (2)
\]

A packed absorber has been investigated, which is recommended to be designed for small-scale production of various technologies. Ventilation emissions are on average 5000 m³/h. At the same time pressure difference in the apparatus is insignificant and short residence time of the absorbent. Nozzles of various shape have considerable contact surface, are laid on support grate in pile or in certain way. The design circuit of the absorber is synthesized in ChemCad.

3. Results and Discussion

During the simulation of the scheme, the following initial data were set: temperature, pressure, flow rate and composition of the gas to be cleaned; temperature, pressure, flow rate and composition of the absorbent; pressure in an absorber; number of theoretical plates in the absorber.
Figure 2a. Dependence of the proportion of hydrogen sulfide ($H_2S$) in the purified gas on the absorbent flow rate at different temperatures (for consumption: range 1000–4400 kg/h): 1 – $t$=40 °C; 2 – $t$=35 °C; 3 – $t$=30 °C; 4 – $t$=25 °C; 15 – $t$=20 °C.

Figure 2b. Dependence of the proportion of hydrogen sulfide ($H_2S$) in the purified gas on the absorbent flow rate at different temperatures (for consumption: range 4400–10200 kg/h): 1 – $t$=40 °C; 2 – $t$=35 °C; 3 – $t$=30 °C; 4 – $t$=25 °C; 15 – $t$=20 °C.

Figure 3. Dependence of hydrogensulfide ($H_2S$) fraction in purified gas on absorbent flow rate at different pressure in the absorber: 1 – $p$=1.0 at.; 2 – $p$=1.4 at.; 3 – $p$=1.8 at.; 4 – $p$=2.2 at.; 5 – $p$=2.6 at.; 6 – $p$=3.0 at.

The number of theoretical plates largely determines the weight fraction of hydrogen sulfide in the purified gas and saturated absorbent. On the basis of practical data, the number of theoretical plates is assumed to be 5, since for this number $N$ it is possible to select the diameter and length of the regular nozzle to be used as the contact body.

The thermophysical properties of the absorbent, its temperature and composition also play a significant role in the degree of purification. However, in the operation of the plant, the temperature and pressure of these streams depend on the performance of the absorber-coupled equipment, so a numerical experiment was conducted to determine the required absorbent flow rate, in which the absorber pressure, temperature and absorbent flow rate varied. The results are shown in Figure 2–3.

Therefore, in order to reduce operating costs and increase the operating range of the apparatus, it is most advantageous to accept an absorbent flow rate of 6600 kg/h, a temperature of 40°C, and a pressure in the absorber of 1 at. The design composition of the gas to be purified and purified gas as well as the used absorbent is shown in Table 1.
Table 1. Estimated structures of flows.

| Flow                | Mass fraction of substance |
|---------------------|-----------------------------|
|                     | Air | MDEA | Water | Hydrogen sulfide |
| The gas to be purified | 0.99 | –   | –     | 0.01             |
| Purified gas        | 0.97 | 0.0022 | 0.028 | 0.00178          |
| Absorbent           | –   | 0.45 | 0.5478 | 0.0022           |

In order to select the type of contact devices, it is necessary to calculate liquid and gas flows along the section of the absorber, which are determined by the program when calculating the scheme.

Figure 4. Liquid and steam flow rate along absorber cross-section: 1 – Liquid Consumption, 2 – Steam Consumption.

Calculated flows of liquid and gas in the absorber are shown in Figure 4. Based on the calculated flows, as well as on the data of industrial operation of plants of similar profile, regular structured packing Mellapack 250 Y is used as the contact device, mass exchange characteristics of which are shown in Figure 5.
Figure 5. Mass exchange characteristics of Mellapack 250 Y nozzle.

When analyzing these graphs (Figure 4–5), we will select the height of the nozzle 5 m. After determining the type of nozzle, it is necessary to calculate the pressure drop and the diameter of the apparatus. The pressure drop in the universal modeling program ChemCad is calculated according to a procedure based on the drop-carrying model and taking into account liquid delay. This relationship applies to both random and structured packing and has a good theoretical basis. This procedure is based on the following equations:

$$\Delta p = K_1 R_e^{K_2}; \hspace{1cm} R_e \leq 2100,$$

$$\Delta p = K_3 R_e^{K_4}; \hspace{1cm} R_e \geq 2100.$$  

(3)  
(4)

Where $K_1$, $K_2$, $K_3$, $K_4$ the coefficients included in equations (3) – (4) are determined automatically by the program. The total pressure drop was 0.021 kg/cm$^2$.

3.1 Cleaning of Ventilation Emissions from Organic Solvent Vapors

Lacquers and paints are produced by both small enterprises and quite large holdings. Certain kinds of solvents are used to adjust paints or enamels to the working viscosity. But all organic solvents used are toxic and negatively affect the human body: the number of mutations, severe diseases, among them cancers, allergies, irritation of mucous membranes and eyes, is increasing.

In order to improve the environmental safety of production, it is necessary to clean industrial ventilation emissions from organic solvents. At the same time, the return of most organic compounds contained in emissions to production can significantly improve its technical and economic indicators.

The process of capturing and returning organic solvents from process and ventilation gases to the cycle is of interest to many researchers. In the work [19] were proposed solutions on hardware and technological design of cyclic processes of purification and return to the production cycle of emissions of organic solvents.

| Table 2. Structure of boiling organic absorbent |
|------------------------------------------------|
| Boiling organic absorbent | Absorber inlet concentration, mass % |
| Diesel fuel | 99–98 |
| Butylbenzene | 1–2 |

| Table 3. Composition of saturated absorbent |
|---------------------------------------------|
| Name of a component | Vapor concentration at absorber inlet, vol. % | Concentration in an absorber, mass % |
| | | Water | Brand A DT | Boiling organic absorbent |
| Cyclohexanone | 0.125 | 0.17 | 0.89 | 0.90 |
| Xylol | 0.624 | 0.29 | 3.80 | 3.81 |
| Toluene | 1.442 | 0.16 | 3.18 | 3.23 |
| Water | 2.350 | 99.38 | 0.11 | 0.13 |
| Air | 95.459 | | 0.03 | 0.03 |

| Table 4. Composition of purified gas |
|-------------------------------------|
| Name of a component | Concentration in an absorber, mass % |
| | Water | Brand A DT | Boiling organic absorbent |
| Water | | | |
Cyclohexanone | 0.110 | 0.001 | 0.001
Xylol | 0.600 | 0.057 | 0.056
Toluene | 1.430 | 0.977 | 0.970
Water | 2.470 | 2.730 | 2.728
Air | 95.380 | 96.227 | 96.199

The following liquid water absorbers, Grade A diesel fuel and high boiling organic absorbent were investigated as absorbents. The composition is given in Table 2. The absorbent flow rate was assumed to be 1 m$^3$/h, and the gas flow rate to be cleaned was assumed according to practical data [15].

The data of Tables 3–4 show that water is the worst solvent because it is practically immiscible with hydrocarbons. Boiling organic absorbent and Grade A diesel fuel show similar results. The choice between them is determined by economic criteria and these data show that water is a bad solvent since it is not mixed with hydrocarbons. When water and boiling organic absorbent are compared, boiling organic absorbent is 5.3 times higher for cyclohexane, 13 times for xylene and 20 times for toluene. In addition, water is a valuable resource and water-saving technologies are promising. Grade A and boiling organic absorbent diesel have sufficient absorbency and show similar results, but the addition of butylbenzene increases the absorption of the captured components.

4 Conclusions

When designing a scheme for absorption purification of ventilation samples from hydrogen sulfide, it is necessary to take into account the chemical reaction of the project. The proportion of hydrogen sulfide recovered in the purified gas is weakly dependent on temperature and pressure. The efficiency of the cleaning determines the composition and flow rate of the absorbent supplied to the absorber.

For absorption cleaning of ventilation emissions from impurities of organic solvents, the most rational solvent is a high-boiling organic absorbent containing diesel fuel of grade A and butylbenzene. Mathematical modeling allows evaluating the selected absorbent and optimizing the absorption process parameters.

The Universal ChemCad Simulation Program allows you to correctly carry out multidimensional calculations of various technological processes, organize and optimize existing ones, evaluate their effectiveness and choose the optimal option.

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