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Hydraulic Resistance in The Mixing Zones of An Absorption Apparatus

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Abstract: The article presents a theoretical study of the mixing zone of a newly developed bubbling absorption apparatus designed for purifying gas mixtures contained in gaseous flows. The static and hydrodynamic processes occurring in the apparatus were investigated, and an equation for calculating the total pressure loss in the apparatus was derived. As a result, based on these pressure losses, the study creates the basis for experimental determination of the purification efficiency of the mixing zone in the apparatus.

Keywords: Static pressure, dynamic pressure, resistance coefficient, bubbling, mixing zone, gas volume, gas velocity, liquid velocity.

INTRODUCTION

The design requirements for absorption apparatuses include ensuring efficient mass transfer between gas and liquid (absorbent), selecting optimal conditions (temperature and pressure) for a specific process, and providing structural solutions that ensure safety, reliability, and operational convenience.

To achieve the maximum degree of absorption, the apparatus must be designed considering the flow directions of both the absorbent and the gas, and it should be selected according to the type of absorption process (physical or chemical).

To fulfill these requirements, researchers must address the following main task [1,2]: to develop improved and advanced designs, along with calculation methods, for absorption apparatuses capable of effectively purifying gases from gas mixtures.

Object of Research

Based on the above requirements and objectives, we have developed a new design of a bubbling absorption apparatus characterized by a simple structural configuration, intensive operating mode, and high efficiency of the mass transfer process [3].

As a result of theoretical studies, an equation was obtained for calculating the gas cushion in the gas distribution section of the apparatus [1,4,5]. The next task of the research was aimed at deriving an equation for calculating the total pressure losses, that is, the hydraulic resistances, occurring in the mixing zones of the apparatus.

The schematic diagram for calculating the total pressure losses in the mixing zones is shown in Figure 1.

Results

In the structural design of the apparatus, the gas and liquid flows move in a co-current direction. To increase the efficiency of the gas purification process, two perforated plates with small holes were installed in the mixing zone.

In the calculation scheme shown in Figure 1, the cross-sections I–I, II–II, and III–III were analysed using Bernoulli's method to examine both the static and hydrodynamic pressures. The total hydraulic resistance of the apparatus can be expressed as follows (in Pa):

$$\Delta P_{ум} = P_c + P_1 + P_2 + P_3 \quad (1)$$

Here, P_s is the *static pressure* in the I–I section of the mixing zone of the apparatus, which is determined by the following equation (in Pa):

$$P_c = \rho_{аб} \cdot g\left(H_0 - \varphi_0\right) \quad (2)$$

Here, ρ_ab is the density of the absorbent (kg/m³); g is the acceleration due to gravity (m/s²); H_0 is the height of the bubbling tube (m); and ϕ_0 is the gas holdup in the bubbling tube.

The gas holdup depends on the physical properties of the gas and liquid as well as their velocities. Therefore, when calculating the gas content, different types of equations are used depending on the type of bubbling absorption apparatus [2].

For the device under investigation, the following equations are applied. Depending on the flow pattern of the gas–liquid mixture, additional characteristics arise — namely, the ratio between the *apparent velocity* of the liquid (w_l) and its *actual velocity* (u_l) can be expressed in terms of the gas holdup as follows:

$$\frac{\omega_c}{u_c} = 1 - \varphi \quad (3)$$

Due to the difference in the densities of the phases, the actual velocities of the gas and liquid ($u_a$ct) differ from each other as a result of the buoyant force acting between them.

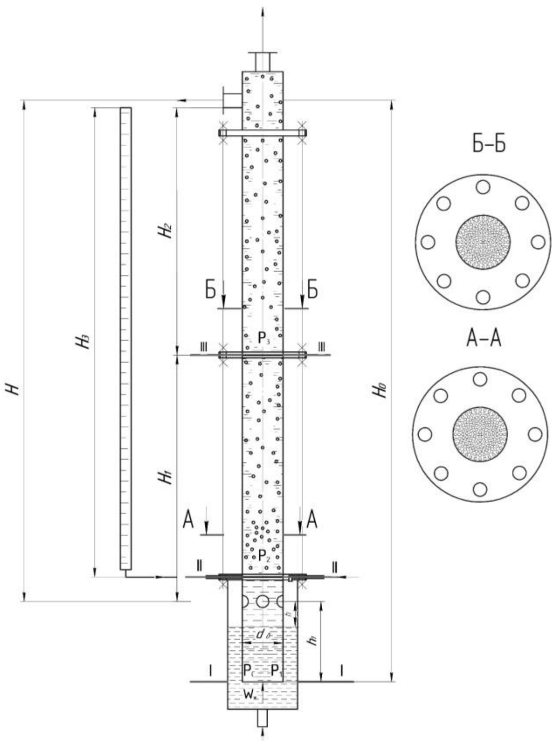

Figure 1. Calculation scheme of the absorption apparatus

When the gas–liquid mixture rises upward, the actual velocity can be determined by the following equation:

$$u_{хак} = u_Г - u_c = \left(\frac{\omega_Г}{\varphi_Г}\right) - \left(\frac{\omega_c}{\varphi_Г - 1}\right) \quad (4)$$

Would you like me to continue with the formula and subsequent explanation that follow this line (the downward flow velocity equation)?

$$u_{хак} = u_c - u_Г = \left(\frac{\omega_c}{1 - \varphi_Г}\right) - \left(\frac{\omega_Г}{\varphi_Г}\right) \quad (5)$$

Based on these conditions, in the intensive operating mode of the bubbling absorber under study, the gas holdup in the mixing zones can be determined by relating it to the gas holdup in the liquid at rest, through the liquid velocities in the internal and external mixing zones of the apparatus [2].

When the gas and liquid flows move co-currently, the gas holdup **ϕ_0** is determined as follows:

$$\varphi_0 = \left(1 - 0{,}04 w'_c\right)\varphi' \qquad (6)$$

Here, w_ab is the velocity of the absorbent moving inside the bubbling tube (m/s), and φ' is the gas holdup of the absorbent in a stationary state, which is determined by the following equation:

$$\varphi' = 2{,}47 \cdot w_г^{0{,}97} \quad (7)$$

Here, w_9 is the apparent velocity of the gas moving inside the bubbling tube (m/s).
Here, P_1 is the hydraulic resistance at the inlet of the absorbent into the bubbling tube, which is determined by the following formula (in Pa):

$$P_1 = \xi_1 \frac{\rho_{аб} \cdot w_{аб}^2}{2} \quad (8)$$

Here, **ξ_1** is the total resistance coefficient at the inlet of the absorbent into the bubbling tube, which consists of the sum of three components and is determined by the following equation:

$$\xi_1 = \xi_б + \frac{1}{(1-\varphi)^2} + \lambda \frac{h_1}{d_б} \quad (9)$$

Here, ξ_β is the resistance coefficient of the absorbent at the inlet of the bubbling tube; ϕ is the gas holdup in the bubbling tube; λ is the friction coefficient of the absorbent at the inlet of the bubbling tube; d_β is the inner diameter of the bubbling tube (mm); and m/s denotes the velocity unit.

P_2 is the hydraulic resistance of the absorbent as it passes through the first perforated plate installed in the bubbling tube, and it is determined by the following equation (in Pa):

$$P_2 = \xi_2 \frac{\rho_{ap} \cdot w_{ap}^2}{2} \quad (10)$$

Here, ξ_2 is the resistance coefficient of the perforated plate installed at section II–II of the bubbling tube, which is determined experimentally; ρ_ar is the density of the absorbent–gas mixture moving inside the bubbling tube (kg/m^3); and w_ar is the apparent velocity of the absorbent–gas mixture in the bubbling tube (m/s).
The density of the gas–liquid mixture is determined as follows:

$$\rho_{ap} = \rho_c \left(1 - \varphi_0\right) + \rho_г \cdot \varphi_0 \qquad (11)$$

Here, ρ_l and ρg are the densities of the liquid and gas, respectively (kg/m^3).

P_3 is the hydraulic resistance of the absorbent as it passes through the second perforated plate installed in the bubbling tube, and it is determined by the following equation (in Pa):

$$P_3 = \xi_3 \frac{\rho_{ap} \cdot w_{ap}^2}{2} \quad (12)$$

Here, **ξ_3** is the resistance coefficient of the second perforated plate installed at section III–III of the bubbling tube, which is determined experimentally.
As a result of the theoretical studies, the static and hydrodynamic pressures at sections I–I, II–II, and III–III of the apparatus were determined. The next step is to substitute the values from Equations (2), (8), (10), and (12) into Equation (1), from which the final equation for calculating the total hydraulic resistance of the apparatus (in Pa) is derived.

$$\Delta P_{ум} = \rho_{ap} \cdot g\left(H_0 - \varphi_0\right) + \xi_1 \frac{\rho_{аб} \cdot w_{аб}^2}{2} + \xi_2 \frac{\rho_{ap} \cdot w_{ap}^2}{2} + \xi_3 \frac{\rho_{ap} \cdot w_{ap}^2}{2} \quad (13)$$

Using the derived Equation (10), the total hydraulic resistance in the mixing zones of the bubbling absorption apparatus can be determined.

Conclusion

In this study, the mixing zone of a newly developed bubbling absorption apparatus designed for the intensive purification of gas mixtures was theoretically investigated. The static and hydrodynamic processes occurring within the apparatus were analysed, and an equation for calculating the total hydraulic resistance was derived.

As a result, based on the obtained hydraulic resistance values, experimental studies can be conducted to determine the purification efficiency of the mixing zone of the apparatus.

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