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EFFECT OF EXTERNAL PRESSURES IN DYNAMIC GAS MIXERS

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Виконаний аналіз впливу тиску джерел чистих компонентів, барометричного тиску та тиску на виході газодинамічного синтезатора на концентрації компонентів одержуваних сумішей. Запропоновано спосіб схемної компенсації впливу цих зовнішніх тисків і отримані відповідні залежності для визначення розмірів дозуючих капілярів. Описаний пристрій на основі схеми з вирівнюванням тисків для калібрування аналізаторів газів у крові

Ключові слова: компенсація тисків, капілярний дросель, змішувач потоків, газова суміш, концентрація компонента

Выполнен анализ влияния давления источников чистых компонентов, барометрического давления и давления на выходе газодинамического синтезатора на концентрации компонентов получаемых смесей. Предложен способ схемной компенсации влияния этих внешних давлений и получены соответствующие зависимости для определения размеров дозирующих капилляров. Описано устройство на основе схемы с выравниванием давлений для калибровки анализаторов газов в крови

Ключевые слова: компенсация давлений, капиллярный дроссель, смеситель потоков, газовая смесь, концентрация компонента

1. Introduction

The growth in demand for various gas mixtures of specified compositions is due to the improvement of existing and the development of new technologies in various industries. First of all, this concerns microelectronics, biotechnologies, environmental monitoring, and scientific research [1, 2]. Significant volumes of mixtures are used for checking (calibration) of gas analyzers and chromatographs as well as gas-analysis systems on their basis [3, 4].

Gas mixtures are produced by various methods [5, 6], but an industrial application was achieved by one of the static methods, the method of partial pressures (in high-pressure cylinders), which has become the basis of a centralized system for production of mixtures at gas-filling stations. However, preparation of such complex multi-component gas mixtures of specified compositions and their storage is difficult and sometimes impossible [7]. This applies to the mixtures with components prone to condensation, disintegration, or diffusion through cylinder walls.

Dynamic methods, in contrast to static ones, are devoid of a number of the aforementioned shortcomings [8]. The gas-dynamic throttle method for preparation of complex gas mixtures is promising as multicomponent mixtures of specified compositions can be continuously prepared on its basis at the place of their consumption [9]. However, mainly binary gas mixtures with macro concentrations of components in the range [1; 100] % can be practically prepared by this method.

Synthesis of gas mixtures by the gas-dynamic method is influenced by various factors, mostly these are changes in external pressures: the pressure of pure component sources, barometric pressure, and pressure at the device exit (caused by instability of the mixture consumption). These changes cause deviation of the dosing throttle operating parameters from the nominal resulting in a change in the mixture component concentrations. As a rule, errors in component concentrations occurring in known dynamic gas mixing devices are at a level of 2–3 % [3]. Influence of external pressures, usually an excess pressure at the input of the dosing throttles, is significant, therefore their changes are restrained, although not always sufficiently, by various means of pressure stabilization, [10, 11]. Other methods of reducing influence of external pressures, including stabilization of absolute pressure at the ends of the dosing capillaries as well as compensation for external pressure variations are known as well. However, these methods of eliminating influence of external pressures in gas-dynamic synthesizers require a separate study [9].

2. Literature review and problem statement

The dynamic method for preparation of gas mixtures of a specified composition involves assignment of flow rates for the components mixed by throttles installed in the channels of the mixture components [10].

The most promising dosing throttles of the gas-dynamic mixers are glass capillaries, which have stable flow characteristics [12].

Concentrations in the mixture determine flows of the components metered with the mixer capillaries. Thus, the mass concentration r_i of the i-th component is obtained from dependence:

$$r_i = G_i\left[\sum_{j=1}^{N} G_j\right]^{-1} = \left[1+\sum_{j=1;\, j\neq i}^{N}\left(G_j / G_i\right)\right]^{-1}, \quad (1)$$

where G_i, G_j are the mass flows of N mixed gases in the channels of the i-th and the j-th components, respectively.

As it follows from dependence (1), invariability of concentrations of the mixture components can be provided in two ways:

– stabilization of the component flows;

– maintaining constant flow ratios G_j/G_i.

The first method involves pressure stabilization at the ends of the dosing throttles and thereby ensuring constant flow values. As a rule, either input pressures of the gas components or the pressure differential in the dosing throttles is stabilized [13]. For example, input gas pressures are stabilized in the scheme of the mixer for preparation of respiratory gas mixtures and the ternary mixture components from the throttle outputs enter the chamber and form the corresponding mixture [14].

Pressure at the input of the adjustable throttle in the system for preparation of gas mixtures with micro concentrations of components is maintained with the pressure regulator and pressure at the output is determined by a column of the liquid through which the metered gas is bubbled [15].

In order to reduce the load effect in dynamic systems, in addition to the stabilizing pressure at the throttle inputs with the help of "offtake" regulators, "intake" regulator is installed at the throttle output [10].

In the gas mixing system [16], component pressures in channels are stabilized with the help of separate regulators and mass flow rates are measured in each of them to determine concentration.

For environmental monitoring, gauging gas mixtures are prepared by means of an installation in which channels contain in-series connected pressure regulators, a Molbox/Molbloc block and a mass flow controller. The metered components are mixed in a chamber to form a gas mixture of a specified concentration [17].

Because of non-identity of characteristics of the pressure regulators used at the inputs and the use of another type of regulator at the output, disproportionate (or even multidirectional) pressure variations occur at the ends of the dosing capillaries. This leads to disproportionate changes in the component flows and therefore to a deviation of concentrations from specified values. Consequently, this method does not ensure high accuracy of maintaining concentration of the mixture components.

Another way of maintaining concentration constancy is to provide unidirectional pressure changes (proportional for full compensation) at the inputs of all dosing capillaries. This requires the same operating conditions for the capillaries, in particular, pressure at their inputs. For example, equality of input pressures in the mixer channels is determined by difmanometer readings [18]. However, the same operating conditions for dosing throttles do not yet provide full compensation for the pressure changes because of non-identity of curvature of the throttle flow characteristics. Therefore, in order to significantly reduce the effect of external pressure changes, it is necessary to investigate dependence of this effect on the size of the flow channels in dosing capillaries.

Consequently, development of gas-dynamic synthesizers using dosing capillaries which would enable compensation of the effects of external pressures should be considered promising. This, in particular, will also ensure replaceability of high-precision stabilizers with typical regulators and preparation of mixtures with admissible deviations of the component concentrations.

3. The study objective and tasks

This study objective was to reduce component concentration errors in the mixtures obtained by the use of gas-dynamic synthesizers through compensation of the effect of changes in external pressures.

To achieve the goal, the following tasks were set:

– to investigate influence of external pressures on concentration of mixture components for the main types of schemes of the flow summarizer;

– to determine conditions for minimizing influence of external pressures on the concentration of components;

– to develop a high-precision synthesizer of gas mixtures for calibrating blood analyzers.

4. Construction and study of schemes of the gas-dynamic synthesizers

The scheme of gas-dynamic synthesizers is constructed on the basis of a flow summarizer (Fig. 1, *a*), the channels of which contain throttle elements Tr_i (nozzles, diaphragms, watch jewels, capillary tubes) dosing corresponding gas components Gas_i (i=1,...,N) of synthesized mixtures. Pressures P_{vi} are assigned at the throttle Tr_i inputs which are usually different. Pressure P_w in the throttle Tr_i outputs integrated in one channel is maintained greater or equal to atmospheric pressure P_0. This is how the throttle elements use capillary tubes *CE:*

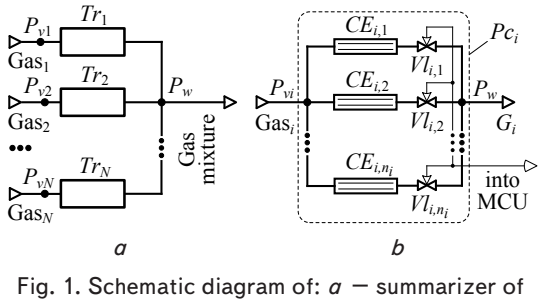

Fig. 1. Schematic diagram of: *a* – summarizer of *N* flows of the mixture components; *b* – package with a sample of capillaries

The flow of the i-th component of the gas mixture through the capillary CE_i is a function $G_i=f(d_i, l_i, P_{vi}, P_w, T, \mu_i, R_{gi}, \xi)$.

Parameters of this function include geometric dimensions of the capillary diameter d_i and length l_i of its passage channel, absolute input and output pressures (P_{vi}, and P_w), absolute temperature T, dynamic viscosity μ_i, gas constant R_{gi} and coefficient ξ of end effects [9].

Dimensions of the passage channels of capillaries belong to the ranges of their permissible values, in mm: $d \in [0.05; 0.5]$ and $l \in [5; 150]$ [12].

To expand the range of the component concentrations of the synthesized mixtures in the channels of the flow summarizers to the place of individual throttles Tr_i (capillaries CE_i), packages of Pc_i capillaries are installed. Such a package (Fig. 1, *b*) is a parallel connection of the capillaries $CE_{i,j}$ (j=1,...,n_i) and an electromagnetic valve $Vl_{i,j}$ is installed at the output of each capillary. Activation of a certain combination of valves $Vl_{i,j}$ involves corresponding dosing capillaries forming flow G_i in the channel of the i-th component which ensures preparation of a mixture of the specified composition.

4. 1. Summarizer of binary mixture

Changes in external pressures influence in various ways concentration of components of the resulting mixtures depending on the scheme and dimensions of the capillaries. Therefore, it is necessary to determine the impact of these factors and develop measures for its reduction (compensation). It is advisable to perform study of the schemes of binary mixture synthesizers and extend the obtained results to N-component synthesizers.

The influence of external pressures P_{v1}, P_{v2} and P_w on concentrations of components was studied at deviations Δ_P=500 Pa in the case of the use of typical means, i.e. pressure regulators of SDG type [19]. Effect of barometric pressure P_0 was investigated at its change by Δ_{P0}=2 kPa.

Fig. 2 shows two main types of the schemes of flow summarizer with various ways of pressure setting at the inputs of dosing capillaries.

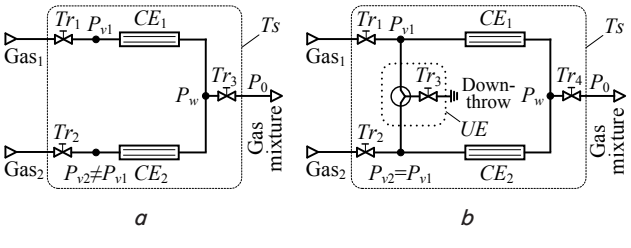

Fig. 2. Schemes of two flow summarizer with pressures at the inputs of the dosing capillaries being different (*a*) or equal (*b*)

In the diagram of Fig. 2, *a*, components Gas_1 and Gas_2 from the sources of compressed gases flow through in-series connected alternating throttle (Tr_1 and Tr_2 respectively) designed for smoothing changes in supply pressures and an accurate setting of the specified input pressure (P_{v1} and P_{v2}) and the dosing capillary (CE_1 and CE_2). The input pressures for the synthesis of mixtures with significantly different (up to two orders of magnitude) concentrations of components are set in general by different ($P_{v1} \neq P_{v2}$). A variable throttle Tr_3 is installed at the output of the flow summarizer to ensure precise setting of P_w pressure. All elements of the synthesizer are placed in a thermostat *Ts*.

Influence of external pressures (P_{v1}, P_{v2}; P_w; P_0) on concentrations (r_1, r_2) of the components of the binary mixture was investigated for various dimensions (d_1, l_1; d_2, l_2) of the dosing capillaries CE_1 and CE_2 of the flow summarizer. Dependences for determining dimensions of the passage channels of the capillaries were derived from the flow characteristics [12].

The values of dimensions (d_1, l_1) of the capillary CE_1 are such as to determine the flow rate G_1 of the Gas_1 component in the mixture at an absolute temperature T of the metered gas and the pressures P_{v1} at the input and P_w at the output of the capillary. In this case, one of the dimensions, for example d_1, is chosen from the range of allowable values so that the determined length

$$l_1 = \left(a_{l1}\xi d_1^4 B_1 X_1 G_1^{-1} - a_{l1}^{-1} G_1\right)/2$$

belongs to the aforementioned range of permissible lengths l; $a_{l1}=4\pi\mu_1/\xi$; $X_1 = \left(512 R_{g1} T \mu_1^2\right)^{-1}$; $B_1 = P_{v1}^2 - P_w^2$.

The dimensions (d_2, l_2) of the capillary CE_2 are such that they set the flow G_2 ($G_2=G_1 r_2/r_1$) and concentration r_2 of the Gas_2 component at pressure P_{v2}. In this case, for example, diameter is determined for the length l_2 selected from the range of permissible values

$$d_2 = \left(\left[4\pi\mu_2 X_2 B_2\right]^{-1} l_2 G_2 \left[G_2 A_2^{-1} + 2\right]\right)^{1/4};$$

$A_2=a_{l2}l_2$, $X_2 = \left(512 R_{g2} T \mu_2^2\right)^{-1}$; $B_2 = P_{v2}^2 - P_w^2$. Similarly, other dimensions (d_2, l_2) of the capillary CE_2 are obtained from the ranges of allowable values and the dimensionless parameter K_{12} is determined. This parameter is the ratio of the complex $K_1 = \xi d_1^4 l_1^{-2}$ of capillary CE_1 and complex $K_2 = \xi d_2^4 l_2^{-2}$ for the determined dimensions of CE_2, i. e.

$$K_{12} = K_1 / K_2 = d_1^4 l_1^{-2} / \left(d_2^4 l_2^{-2}\right).$$

The following are the results obtained in the study of the binary mixture synthesizer scheme for 10 % CO_2 in N_2 at absolute pressure values: P_{v1}=115 kPa and P_{v2}=150 kPa, P_w=105 kPa and P_0=100 kPa. Temperature T of the components was stabilized at a level of 310 K.

Fig. 3, *a* presents graphs of dependence of the relative error δr_1 of CO_2 concentration on the design complex K_{12} of the synthesizer capillaries during the change of external pressures. Graphs 1 and 2 were derived respectively for the input pressures: $P_{v1}-\Delta_P$ and $P_{v2}+\Delta_P$ (1); $P_{v1}+\Delta_P$ and $P_{v2}-\Delta_P$ (2); graphs 3 and 4 for the output pressures $P_w+\Delta_P$ and $P_w-\Delta_P$, and graphs 5 and 6 were obtained at the change of barometric pressure $P_0+\Delta_{P0}$ and $P_0-\Delta_{P0}$.

As it follows from the graphs (Fig. 3, *a*, *b*), the influence of external pressures on concentration of components is significant. For example, the total boundary relative error δr_1 of CO_2 concentration in the mixture makes 8 % and the mean square error makes 5.7 %. However, as can be seen from the graphs in Fig. 3, *a*, influence of these factors hardly depends on the dosing capillary structures (parameter K_{12}), hence it is impossible to compensate for the effect of these factors by selection of dimensions. Similar results were obtained for other binary mixtures with various component concentrations.

Similar studies were performed for the throttle scheme shown in Fig. 2, *b* with pressure equalization ($P_{v2}=P_{v1}=P_v$) at the inputs of the capillaries and shown below for the mixture (10 % CO_2+N_2). Pressures at the inputs of capillaries CE_1 and CE_2 are equalized by means of the assembly *UE* containing a tee with a variable throttle Tr_3 at the output through which a part of flow of each component is discharged. The tee inputs

are connected to the inter-throttle chambers, one of which is formed by the variable throttle Tr_1 and the capillary CE_1, and the other is formed by Tr_2 and CE_2. The gas-dynamic resistances of the variable throttles Tr_1, Tr_2, and Tr_3 are chosen so as to prevent flow of one component into the channel of the other component.

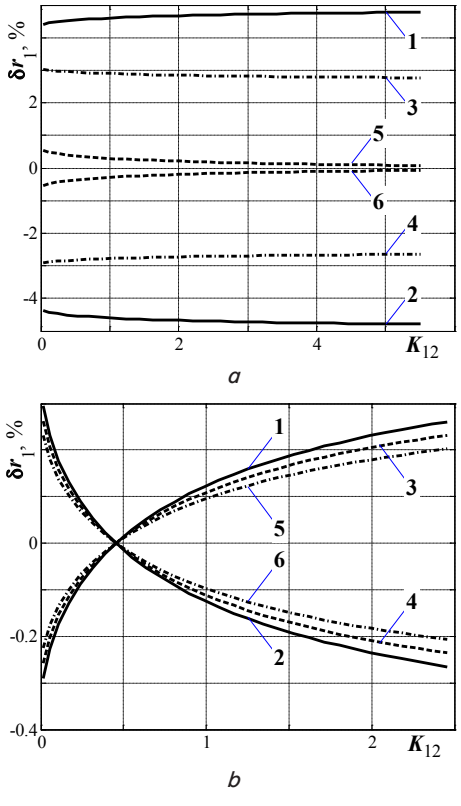

Fig. 3. Graphs of dependence of relative error $\delta r_1(K_{12})$ at the change of external pressures of the flow summarizers: *a* — with different pressures at the capillary inputs; *b* — with equal pressures at the capillary inputs

Graphs of dependence of δr_1 of the CO_2 concentration on K_{12} are shown in Fig. 3, *b* for a scheme with equalizing of pressures P_v of the flow summarizer when external pressures change. Graphs 1 and 2 for the respective input pressures $P_v+\Delta_P$ (1) and $P_v-\Delta_P$ (2), graphs 3 and 4 for output pressures $P_w+\Delta_P$ and $P_w-\Delta_P$ and graphs 5 and 6 for a change in barometric pressure $P_0+\Delta_{P0}$ and $P_0-\Delta_{P0}$ were obtained.

As it follows from the graphs in Fig. 3, *b*, influence of pressures on concentration of the mixture components is an order of magnitude smaller than in the case of preparing a mixture with a synthesizer based on the scheme with the flow summarizer presented in Fig. 2, *a*. The total limiting error δr_1 does not exceed 0.8 % and the mean square error does not exceed 0.5 %. In addition, it is clear from the graphs that the capillaries for which $K_{12}\approx 0.45$ compensate for the influence of external pressures.

It follows from the results of the study that the synthesizers built on the basis of the first scheme presented in Fig. 2, *a* need high-precision means of external pressure stabilization for their operation. The scheme with pressure equalizing can operate in a wide range of variation of the external pressures (without high-precision means of their stabilization) and ensure compensation.

4. 2. Minimizing effect of external pressures

To compensate for the effects of external pressures as set forth above, it is necessary to equalize pressures at the capillary inputs. The capillary dimensions ensuring independence of concentrations of the binary mixture components from the pressure changes are determined from the condition

$$\sum_{j=1}^{3}\partial r_1/\partial p_j=0, \tag{2}$$

where $p_j\in\{P_v; P_w; P_0\}$.

According to the dependence (1) and taking into account the expression for the gas flow through the capillary [9], concentration r_1 can be represented as

$$r_1=\left[1+G_2/G_1\right]^{-1}=\left[1+\frac{A_2}{A_1}\frac{\left(1+Y_2B\right)^{1/2}-1}{\left(1+Y_1B\right)^{1/2}-1}\right]^{-1}, \tag{3}$$

where, besides the known, $A_i=a_{li}l_i$; $Y_i=K_iX_i$; $i=1,2$ is the index of the mixture component; $B=P_v^2-P_w^2$; $P_v=\Delta P_v+P_0$; $P_w=\Delta P_w+P_0$; ΔP_v and ΔP_w are overpressures at the capillary input and output respectively.

After substitution of partial derivatives in expression (2), K_{12} is obtained at which there is no influence of pressures on the mixture component concentrations:

$$K_{12}=K_1K_2^{-1}=X_1^{-1}X_2=R_{g1}R_{g2}^{-1}\mu_1^2\mu_2^{-2}. \tag{4}$$

As it follows from condition (4), the K_{12} complex only depends on the thermal-physical parameters of the metered gases and does not depend on the external pressures and concentrations of the mixture components.

For ease of use, it is expedient to represent condition (4) in a form of two equations one of which relates the lengths, and the other relates diameters of the capillary channels with concentrations and thermal-physical parameters of the mixture components. To this end, the relation (4) is presented as equality $Y_1=Y_2$ which upon taking into account expression (3) and transformations forms a system for determining dimensions of capillaries of the flow summarizer for two laminar gas streams:

$$\left.\begin{aligned} &l_2=\left[r_1^{-1}-1\right]\mu_1\mu_2^{-1}l_1;\\ &d_2=\left[r_1^{-1}-1\right]^{1/2}\left[R_{g1}^{-1}R_{g2}\right]^{1/4}d_1;\\ &4G_i\left[\pi\mu_i d_i\right]^{-1}\le 2320. \end{aligned}\right\} \tag{5}$$

Consequently, the calculation of capillaries based on system (5) ensures full compensation for the influence of external pressures on the concentrations of components of the synthesized binary mixture.

4. 3. Effect of deviations of the capillary dimensions from the calculated dimensions

In practice, the values of the calculated dimensions of the capillary passage channels can be only obtained with a certain error. For example, measurement of the capillary channel length l by micrometric means is performed with an absolute error $\Delta_l=0.01$ mm which corresponds to a relative error of 0.2 ... 0.07 % for the capillaries from the range of acceptable lengths.

The capillary diameter d affects the flow much more than the length since it is included in the fourth power in its flow characteristic. Measurement of the internal diameter of capillaries in the range of 0.05...0.5 mm is a complex task since the passage channel is not strictly cylindrical. In this connection, while the proposed gas-dynamic method provides relative error δ_d of diameter determination at the level of 0.6 % [20], the corresponding absolute error (in mm) is $\Delta_d=\delta_d \cdot d=3\cdot10^{-4}$ ... $3\cdot10^{-3}$.

Taking into account the errors in measuring the lengths of capillaries and determining their diameters, the errors in specifying concentration of components for a mixture of 10 % CO_2 in N_2 were estimated and the effect of external pressures on the component concentrations was studied.

It was established that for the flow summarizers of the both schemes presented in Fig. 2 under nominal pressure, the dosing capillaries $\{d_1\pm\Delta_{d1}, l_1\pm\Delta_l; d_2\pm\Delta_{d2}, l_2\pm\Delta_l\}$ ensure concentration of CO_2 with a limiting relative error δr_1 at the level of ±4 %. In this case, dimensions (in millimeters) of the flow summarizer capillaries from Fig. 2, *a* calculated as described above were d_1=0.12, l_1=9.74 for capillary CE_1 and $d_2\in$[0.1979; 0.3073], $l_2\in$[5; 150] for capillary CE_2 [5; 150]. Dimensions of the flow summarizer capillaries from Fig. 2, *b* determined from the system (5) were (in millimeters) d_1=0.08, l_1=5.14; d_2=0.2687, l_2=39.10.

Limit deviations Δr_1 of concentration r_1 resulted from the changes in external pressures were determined which for the input, output and barometric pressures in the schemes with the input pressures were (in % abs/kPa):

– different: $\Delta r_1(\Delta P_{v1}, \Delta P_{v2})\approx1$; $\Delta r_1(\Delta P_w)\approx0.6$; $\Delta r_1(\Delta P_0)\approx0.03$;

– equal: $\Delta r_1(\Delta P_v)\approx2\cdot10^{-3}$; $\Delta r_1(\Delta P_w)\approx1.5\cdot10^{-3}$; $\Delta r_1(\Delta P_0)\approx4\cdot10^{-4}$.

Consequently, the scheme of the flow summarizer with pressure equalizing and dosing capillaries having dimensions determined by the system (5) ensures synthesis of mixtures in which component concentrations are practically independent of the changes in the external pressures. Since it is impossible to ensure in practice the calculated capillary dimensions, an error of setting concentrations arises. However, this error can be reduced by shortening the channel length for one of the capillaries according to the results of measuring the mixture component concentration with the help of a gas analyzer installed at the synthesizer output.

4. 4. Mathematical model of the flow summarizer for a multicomponent mixture

The N-component mixture can be presented as a composition of N-1 binary mixtures, each containing, for example, a component with a maximal concentration in the multicomponent mixture. Then the N-component gas mixture (Gas_1+Gas_2+...+Gas_N) with the highest concentration r_1 of the component Gas_1 and concentrations $r_2,...,r_N$ of the rest components can be considered an aggregate of N-1 binary mixtures like (Gas_1+Gas_2)+...+(Gas_1+Gas_N).

To determine concentration of r_{bi} of the i-th component of the binary mixture (Gas_i+Gas_j), it will suffice to take into account the fact that the flows G_i and G_j of the corresponding components are proportional to the concentrations of r_i and r_j in the multicomponent mixture. Then the dependence (1) for r_{bi} takes the form

$$r_{bi}=\left(1+G_i^{-1}G_j\right)^{-1}=\left(1+r_i^{-1}r_j\right)^{-1} \qquad (6)$$

and concentration of the j-th component of the mixture (Gas_i+Gas_j) is determined as $r_{bj}=1-r_{bi}$.

Making use of the known concentrations of components in the prepared binary mixtures, dimensions of the capillaries for synthesis of a multicomponent mixture are determined.

The system based on (5) supplemented by the equation (6) provides determining dimensions of the flow summarizer capillaries for N components with concentrations $r_1,...,r_N$:

$$\left.\begin{aligned} &l_j=\left[r_{bi}^{-1}-1\right]\mu_i\mu_j^{-1}l_i;\\ &d_j=\left[r_{bi}^{-1}-1\right]^{1/2}\left[R_{gi}^{-1}R_{gj}\right]^{1/4}d_i;\\ &r_{bi}=\left[1+r_j r_i^{-1}\right]^{-1};\ r_{bj}=1-r_{bi};\\ &\max\left\{4G_i\left[\pi\mu_i d_i\right]^{-1}\right\}\le 2320, \end{aligned}\right\} \qquad (7)$$

where, in addition to the known, d_i, l_i are respective diameter and length of the capillary CE_i with known (specified) dimensions in the channel of the i-th component; d_j, l_j are the determined dimensions of the capillary CE_j in the j-th component channel.

Channel dimensions for the rest of capillaries can be determined not only through one specified dimension, but through any other dimension, which was already calculated at a certain iteration.

If the calculated dimensions of the capillary are beyond the upper limit of the range of acceptable dimensions, then this capillary is replaced with an equivalent package of capillaries [21]. The packages may have capillaries both of the same dimensions (the same flows) and the dimensions that provide multiple flows. To compensate for effects of external pressures, flow characteristics of the capillaries from the package should have the same curvature as the capillary to be replaced. For practical reasons, the number of capillaries in the packages should be limited to two dozen but the use of such packages still does not ensure achievement of low concentration ranges (e. g. r<0.01 %).

5. Gas-dynamic synthesizer for calibrating the blood analyzer

Gas mixtures of specified compositions are used for checking gas analyzers, in particular, blood analyzers. To calibrate electrodes of Radiometer Medical analyzers, the following mixtures are used: a binary mixture (11.22 % CO_2) and a three-component mixture (19.76 % O_2 and 5.60 % CO_2 in N_2) [22].

Fig. 4 shows a diagram of the developed synthesizer of the binary and three-component mixtures which has three inputs (i=1, 2, 3) for pure gases (O_2, CO_2 and N_2). The i-th component passes via a corresponding channel through in-series connected stabilizer Sp_i of over-pressure, a variable throttle Tr_i and a heat exchanger HE_i which provides temperature T=310±0.2 K for the components and all elements of the synthesizer equal to the thermostat Ts temperature.

Next, the corresponding components are dosed out with capillaries: O_2 with capillary CE_1, N_2 with capillary CE_3, and CO_2 with capillaries $CE_{2,1}$ and $CE_{2,2}$ from the package Pc. The pressures at the inputs of the capillaries are equalized using units UE_1 and UE_2 (Fig. 2, *b*). Pressure $P_w>P_0$ is set at the outputs of the capillaries with the variable throttle Tr_4. To prepare a binary mixture, dosing capillaries $\{CE_{2,2}; CE_3\}$ are engaged by activating the "normally closed" electromagnetic valves $\{Vl_{2,2}; Vl_3\}$. To obtain a ternary mixture,

capillaries {CE_1; $CE_{2,1}$; CE_3} are engaged by activating valves {Vl_1; $Vl_{2,1}$; Vl_3}. The microprocessor unit MCU controls the synthesizer's operation.

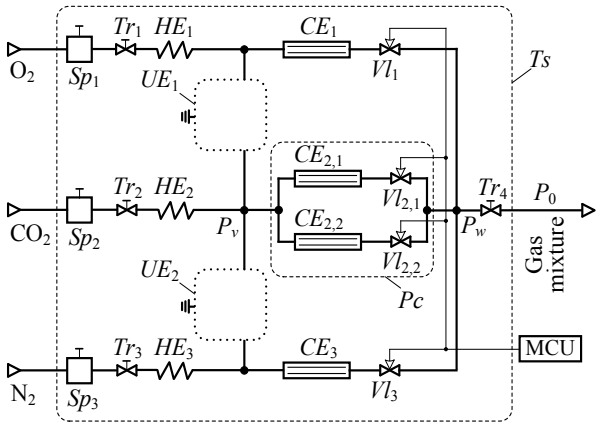

Fig. 4. Schematic diagram of the synthesizer for preparation of calibrating gas mixtures (CO_2+N_2) and (CO_2+O_2+N_2)

Dimensions (in mm) of the dosing capillaries of the synthesizer calculated by the system (7) are as follows: d_1=0.12, l_1=30.00; $d_{2,1}$=0.0590, $l_{2,1}$=11.65 and $d_{2,2}$=0.0766, $l_{2,2}$=19.62; d_3=0.2411, l_3=131.32.

The dosing capillaries with calculated dimensions are manufactured with the abovementioned errors resulting in the problem of setting component concentrations in the mixture. The maximum relative error of setting concentrations of the component with the smallest content in the mixture does not exceed 5 %.

The deviations in component concentrations resulting from the change in external pressures which do not exceed $4{\cdot}10^{-3}$ % abs/kPa indicate actual independence of concentration from the changes in external pressures.

Consequently, the errors of dimensions of the dosing capillaries of synthesizers for both binary and ternary mixtures cause deviations at a level of several percent of the specified values of the component concentrations (the specifying error). However, the ratio of component flows remains virtually insensitive to the changes in external pressures.

6. Discussion of the results obtained in the study of effect of external pressures in dynamic gas mixers

According to the study results, it was found that it is impossible to compensate for the effect of external pressures on the flow summarizer scheme in which different pressures at the flow summarizer inputs are set and maintained by separate stabilizers. The mixture synthesizers built on its basis are characterized by significant influence of external pressures, in particular, for the given example, the limit concentration deviations (in % abs/kPa) of CO_2 Δr_1 from the changes in P_v, P_w and P_0, were 1; 0.6 and 0.03 respectively.

In contrast to the mentioned scheme, the scheme of the flow summarizer with equalizing of the input pressures opens the prospect for making high-precision gas-dynamic synthesizers. Application of such a scheme enables at least partial compensation for the effect of external pressures on the component concentrations for arbitrary designs of the dosing capillaries. This is due to the fact that the input pressures in the scheme change undirectionally and the flows of the metered components of the mixture vary accordingly. Full compensation for the influence of external pressures is possible by ensuring proportionality of changes in the flows of the metered components which can be obtained through a certain ratio of dimensions of the flow summarizer capillaries. This ratio is obtained from the condition (2) of independence of the component concentrations from the influence of external pressures represented by the system (5) for the capillaries of the flow summarizer for binary mixtures and the system (7) for the multicomponent mixtures.

The use of dosing capillaries with channel dimensions differing from the calculated dimensions causes deviation of the component concentrations from the specified values at a level of 4 % abs for the both schemes of the flow summarizers given in Fig. 2. If necessary, this deviation can be reduced by shortening the capillaries during the measuring control of the component concentration in the synthesized mixture with the help of a gas analyzer.

For the flow summarizer with pressure equalization, the limit deviation of the component concentrations resulting from the changes in external pressures is lower by 2 orders of magnitude and therefore it can be assumed that the component concentration is practically independent from variation of these factors. Besides, synthesizers with pressure equalization do not require high-precision stabilization but just a limitation of pressure changes within a certain range which is determined by the design and adjustment of the UE unit.

Consequently, it can be asserted that making of synthesizers based on the scheme with equalizing of the metered component parameters, in particular pressures, is promising. However, clarification of possibility of this scheme application for designing high-precision gas-dynamic synthesizers of mixtures in the ranges with lower component concentrations requires further study.

7. Conclusions

1. Influence of external pressures on the mixture component concentrations for the main types of schemes of the flow summarizers was studied. It was shown that the use of the flow summarizer with pressure equalization at the ends of the dosing capillaries provides a ten times reduction of the relative error in the mixture component concentrations in comparison with the flow summarizer in which the input pressures are maintained by individual stabilizers.

2. A system of equations for determining dimensions of the flow channels in the dosing capillaries of the flow summarizer with pressure equalization which ensure proportionality of changes in the flows of the metered components during the change in external pressures and thus constancy of the component concentrations was obtained. It is also important that the synthesizers constructed on the basis of such a flow summarizer do not require high-level maintenance of pressures or flows.

3. Based on the scheme of flow summarizer with pressure equalization, a high-precision gas-dynamic synthesizer of binary and ternary mixtures was developed for calibrating blood analyzers. The dimensions of the flow channels in the dosing capillaries of the flow summarizer provide independence of the component concentrations in the prepared mixtures from the changes in input, output and barometric pressures.

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