RESEARCH OF LEAK DETECTION SYSTEMS WITH ACCUMULATIVE MEMBRANES

V.M.Mjasnikov, S.G.Sazhin, Dzerzhinsky Polytechnic Institute NSTU named after R.E.Alekseev, Dzerzhinsk, Nizhegorodsky region, Russia

One of the most demanded methods of receiving flaw-detection information concerning the arrangement of leak places of a gas-analyzing group is the probe method. Its essence is that trial gas is fed under pressure into the article, because of the pressure fall it overflows through the leak channel and forms a concentration field over a product surface. Then probe scanning (scanning by a sampler) of the surface of the article is held for the purpose of defining trial gas concentration by selecting the sample and it is transported along a capillary into the leak detection chamber. The leak place is evaluated according to the arrangement of a high concentration zone of trial gas.

When defining places of leaks by the probe method it is necessary to emphasize the problem of revealing small and large leaks. Thus, displacement of the probe from the leak having magnitude of $3.5 \cdot 10^{-8}$ $m^3 \cdot Pa$ /s to the distance of 0.5 mm reduces sensitivity four times. It is connected with the fact that on a control position there are streams of air that dilute the analyzed sample up to the concentration of trial gas that is present in the atmosphere, as a result, the threshold of sensivity decreases. Large leaks like $5.7 \cdot 10^{-3}$ $m^3 \cdot Pa/s$ and more form wide area with the heightened concentration of trial gas, but chaotic air streams that are present on the position of articles test distort the concentration field, reduce accuracy of defining leaks coordinates.

To protect concentration field from external action of ambient air it is expedient to use membranous method; its essence is the following: a membrane with porous structure is imposed on a controllable surface, and selection of the analyzed sample is made from the membrane or from its surface. As leaks form small streams the concentration field is detected by the equation of trial gas diffusion, thus, the less the diffusion constant is, the more the concentration of trial gas will be in the leak neighborhood, as a result, sensitivity of tests increases. The presence of the porous membrane over the surface of the tested article contributes to the decrease of the diffusion constant. It can be traced by the dependence establishing connection between the diffusion constant of trial gas D in porous structure and in the atmosphere:

$$D = D_{a} \cdot \frac{\varepsilon}{T},$$

where D_a - diffusion constant of trial gas in the atmosphere; ε - porosity of membrane material; T - tortuosity of the pores channel in the membrane. Having chosen the porous material with the operation factors $T = 1.5$ and $\varepsilon = 0.4$ it is possible to increase concentration of trial gas in the leak neighborhood in 3.75 times, and, hence, to raise sensitivity of the test.

Research of the influence of porous structure on noise immunity of the concentration field of trial gas leak was made on membranes with spongious structure made of foam rubber by the reticulation method. In the table porometric characteristics of membranes materials are shown.

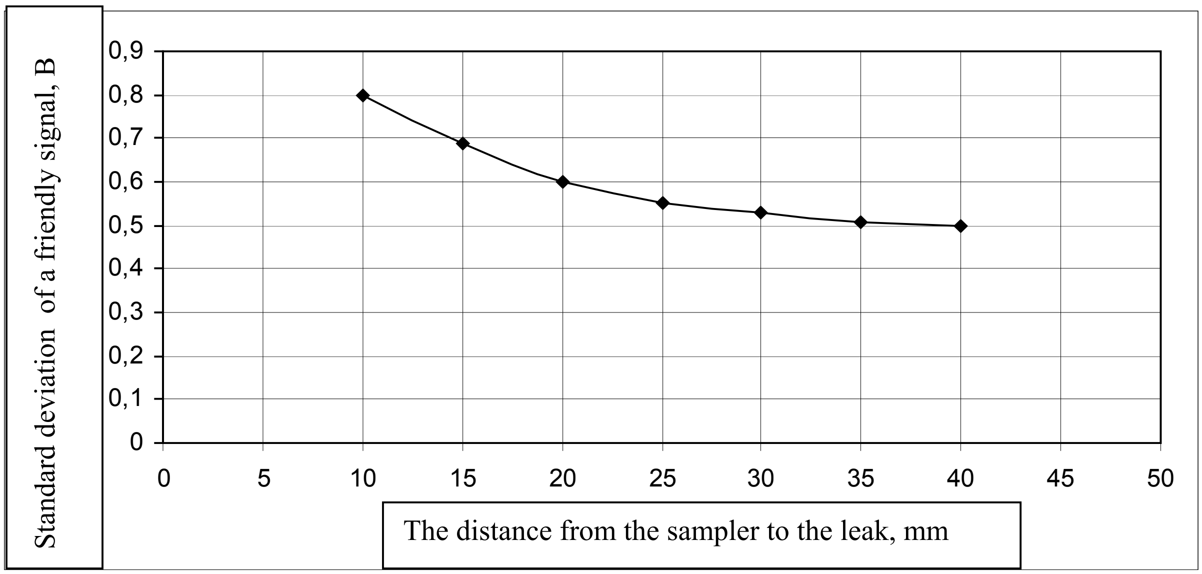
The quantitative estimation of concentration field stability in trial gas leaks was evaluated according to standard deviation of helium mass-spectrometric leak detector indication. For this purpose the control leak of diaphragm type was made by the method of pyrolytic chromium sedimentation from the steam phase of organometallic compound to a metal base plate.

# of the material	Seeming density, kg/m^3	Air permeability at 20 mm Hg (l/hour sm^2)	Diameter of the pores channel, mm
1	30.5	1575	4.1
2	20.9	1438	2.5
3	25.9	650	1.3
4	37.2	35	0.8

The control leak ($7.6 \cdot 10^{-3}$ m^3Pa/s) was calibrated by means of the leak «Helit », was built in a metal sheet simulating the surface of the article and was connected to capacity with helium. The choice of such a large leak is caused by the fact that destabilization of a concentration field from such leaks has pronounced character.

Membranes had thickness from 5 to 45 mm. Selection of the analyzed sample was carried out through a metal capillary with inner diameter of 0.3 mm and length of 2 m, insulating layer is applied to the outside of the capillary expelling instability of stream because of unstable temperature of its walls. The stream of the selected sample was 10^{-3} m^3Pa/s. Such a small stream did not distort the concentration field as area of carrying over the sample due to aspiration of the analyzed sample conformed to 1.5mm.

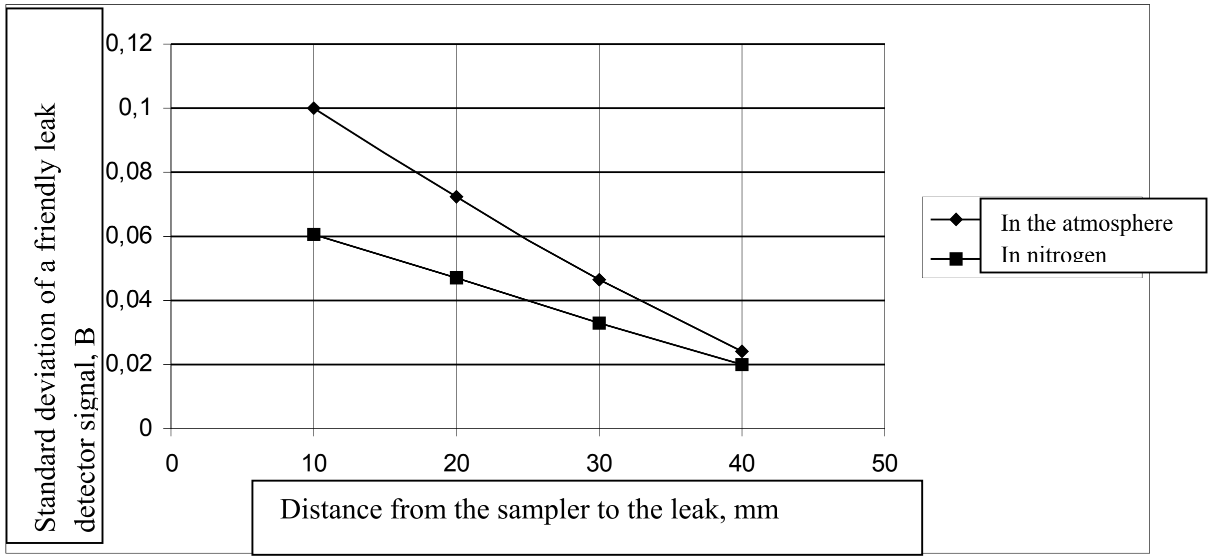
Pic.1 shows the change of standard deviation of a leak detector signal from the distance between the sampler and leak. The concentration field was measured in the atmosphere (without the membrane).



Pic.1. Change of standard deviation of a leak detector signal from the distance between the leak and the probe under the conditions of leak accumulation in the atmosphere (in the absence of a porous membrane).

From the diagram it is visible that as approaching to the leak the spread of the leak detector indication increases. It is explained by the fact that on the periphery of a concentration field the gradient of concentration is less than nearby the leak, therefore insignificant displacement of a concentration field nearby the leak calls sharp change of trial gas concentration and, hence, change of a leak detector signal with time. Increase of trial gas concentration nearby the leak leads to the rise of friendly signal fluctuation as the stream of the trial gas arriving in the chamber of the mass-spectrometric leak detector increases.

The influence of porous medium on noise immunity of a concentration field can be sized up by the results of comparison of standard deviations of the leak detector signal in the process of the concentration field formation directly in the atmosphere (see pic.1) and under the conditions of the concentration field protection in the porous membrane, dependence is shown in pic.2. From this comparison it follows that the standard deviation of the leak detector signal decreases 10 times at leak accumulation in the porous membrane. Research of shielding medium presence on stability of the leak detector indication has been carried out in parallel (see pic.2). Nitrogen was applied as shielding medium.



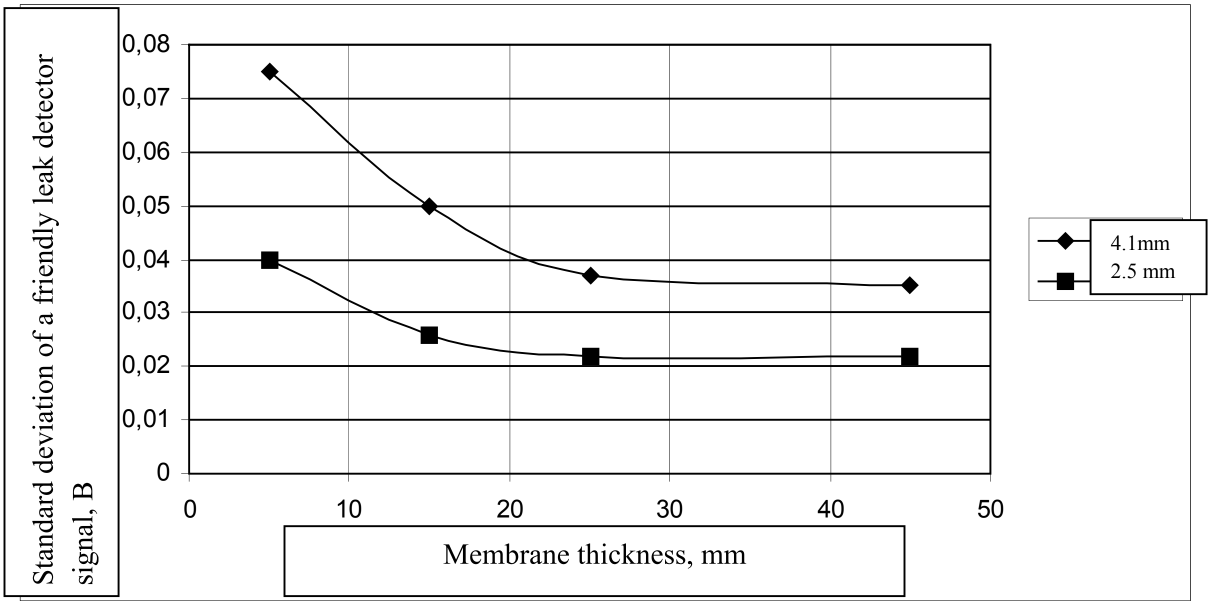
Pic.2. Dependence of standard deviation of a leak detector signal on the distance between the leak and the probe under the conditions of leak accumulation in the porous membrane with thickness of 40 mm, porometric characteristics of material № 4 (see the table) under the conditions of the membrane planes irrigation by nitrogen and in the absence of nitrogen.

The dispersion of the leak detector signal decreases when putting the membrane into the medium with nitrogen. It is explained by the absence of helium concentration on the surfaces of the membrane planes as a result of trial gas outflow. At the same time, boundary conditions varied towards the decrease of helium concentration, it led to the decrease of helium concentration in the membrane. The decrease of helium concentration in the leak detector chamber leads to the decrease of the friendly signal fluctuation.

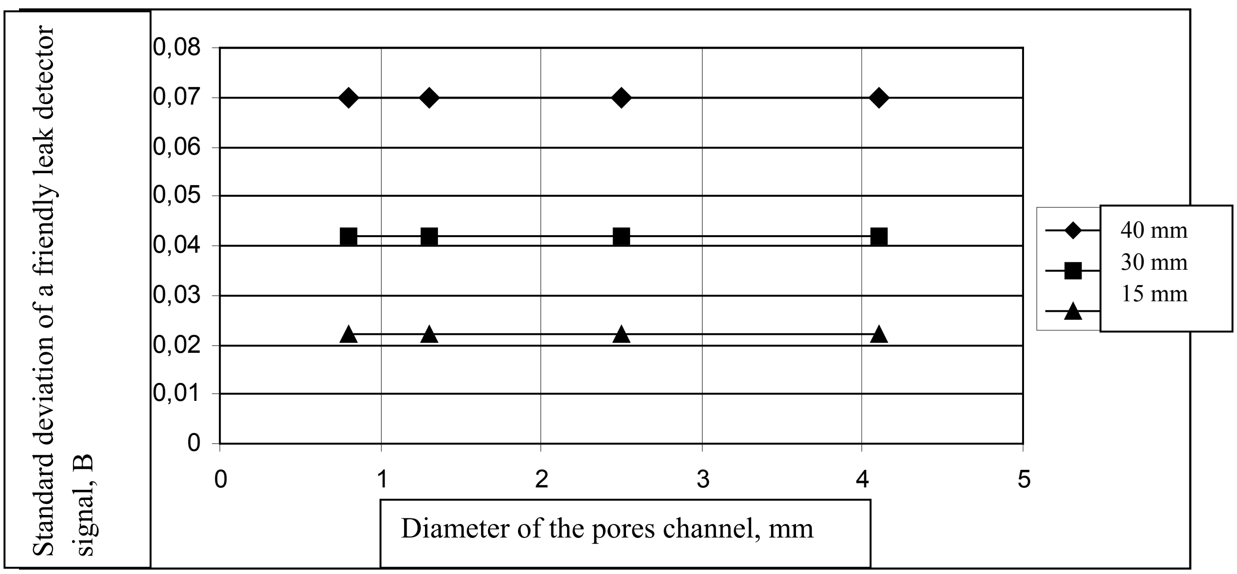
Pic.3 shows the influence of the membrane thickness on noise immunity of the concentration field. Plots are gained with the use of membranes from the material with pores channel diameter D = 4.1 and 2.5 mm. The results of the research proved that noise immunity of the concentration field is provided under the condition that the thickness of membrane H and the pores channel diameter fulfill the inequality $H/D \geq 6$.

Further on, the influence of the porometric characteristics of the membrane material on noise immunity of a concentration field was investigated (pic.4). It is installed as a result that pores diameter to noise immunity is practically absent. Plots are gained at different thickness of membranes. Change of standard deviation of the leak detector signal for different thickness of membranes was affected by boundary conditions of trial gas concentration over the membrane surface. It has led to helium concentration increase in membranes with larger layer thickness and, consequently, to the rise of helium pressure in the leak detector chamber, with helium rise in the chamber friendly signal fluctuation has increased.

As sample selection occurs not in the point of the probe arrangement, but in its neighborhood, the results of measurement will be influenced by characteristics of averaging of trial gas concentration in the analyzed sample. The rightfulness of choosing the method of quasi-homogeneous approximation is experimentally confirmed. This fact is based on regularity of concentration averaging at equal scale of averaging that is characterized by radius of averaging in different points of selection, but on equal removal of the probe concerning the leak.

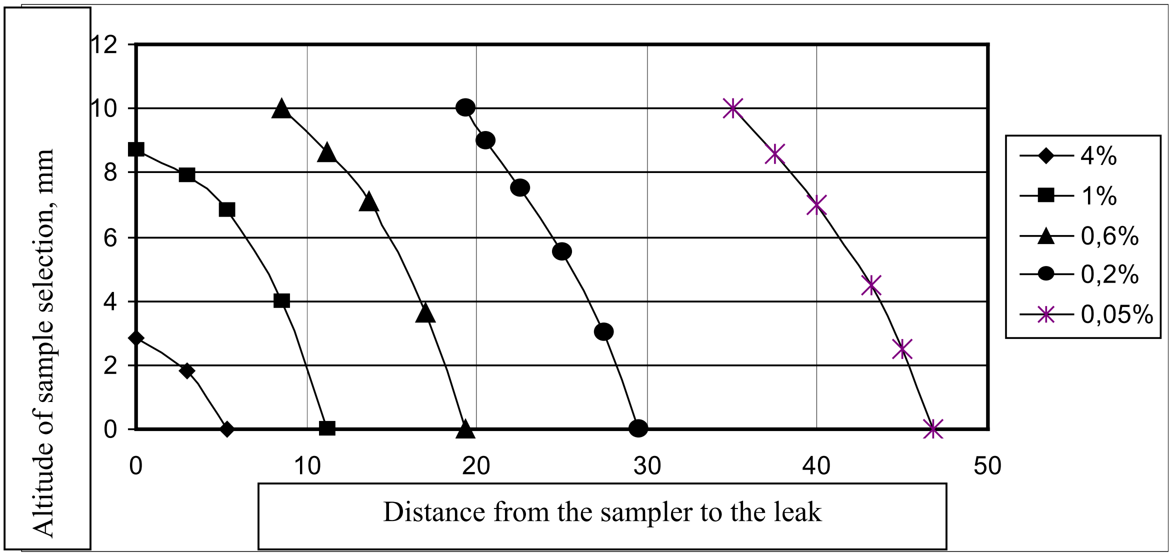


Pic 3. Dependence of standard deviation of a leak detector signal on the membrane thickness with different diameters of the pores channel

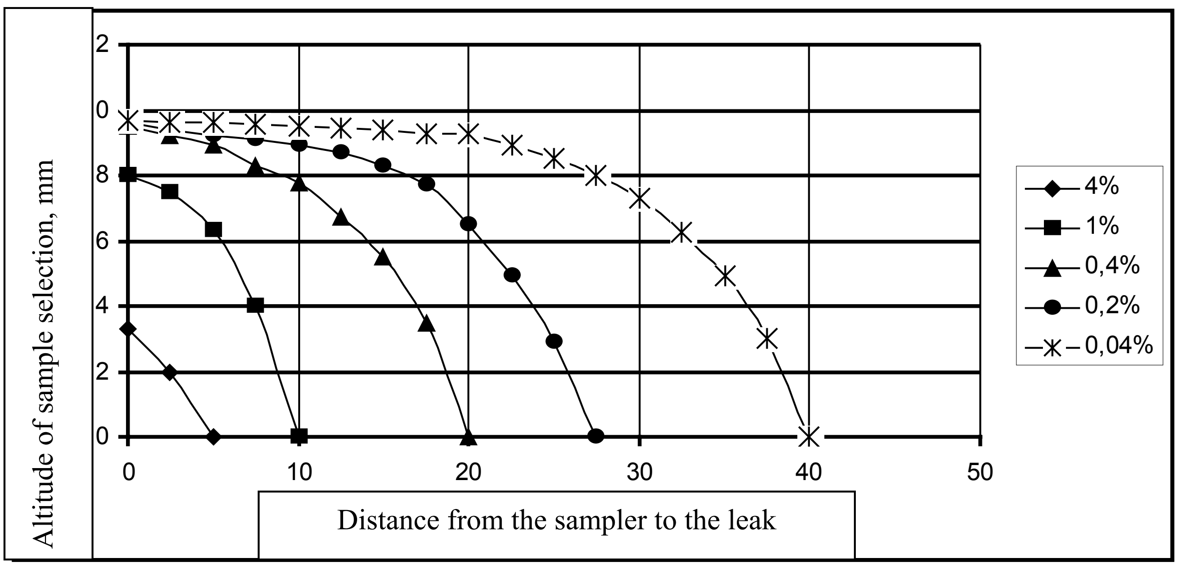


Pic.4. Dependence of standard deviation of a leak detector signal on the diameter of the pores channel at different membrane thickness.

Results of distribution of trial gas concentration in the porous membrane have been simultaneously gained under different conditions of affecting their planes. Pic.5 shows the state of the concentration field when the membrane is disposed directly in the atmosphere, the state in the environment of protective gas (in nitrogen) is shown in pic.6. The impact of a gas-proof film on the concentration field in the membrane is shown in pic.7.



Pic. 5. Distribution of trial gas concentration in the leak neighborhood when the porous membrane planes are affected by air.

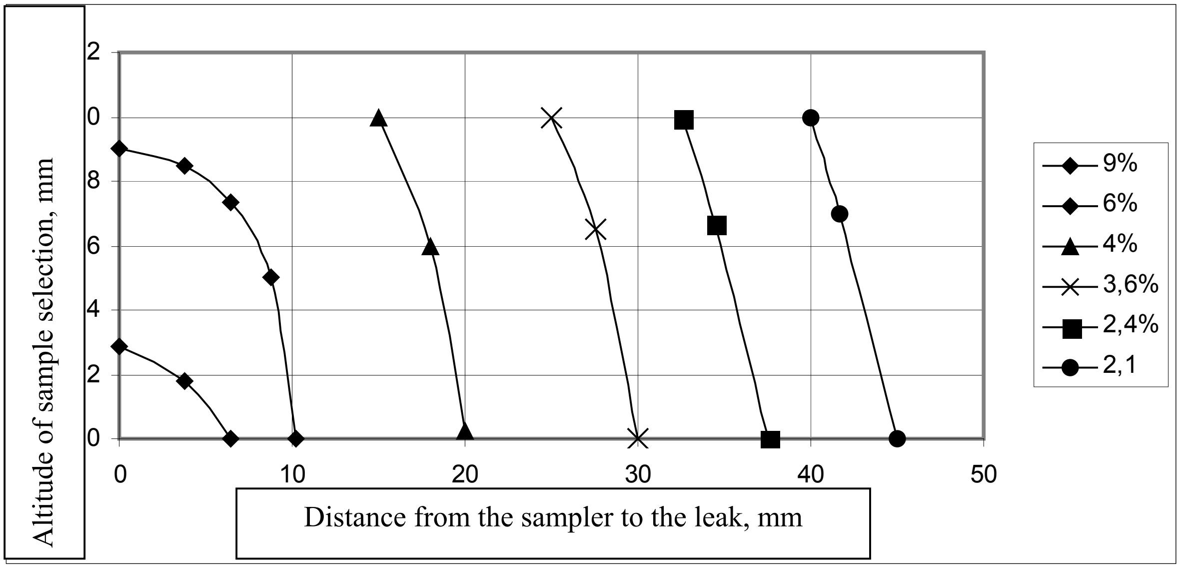


Pic.6. Distribution of trial gas concentration in the leak neighborhood when the porous membrane planes are affected by the medium of protective gas

The installed rate of trial gas distribution in the membrane from leaks in the interval 10^{-3} - 10^{-8} m$^3 \cdot$Pa/s is described by the diffusion equation:

$$D\Delta C = -Q\delta(x - x_l)\delta(y - y_l).$$

Here x_l, y_l are co-ordinates of leaks, x, y - co-ordinates of observation points, Δ - Laplace operator, δ is δ-function, Q - stream of trial gas through the leak.



Pic.7. Distribution of trial gas concentration in the leak neighborhood when a gas-proof sheet is put on the porous membrane plane

Let's mark the length of the membrane - *A*, its width - *B*, its thickness -*H*. To define boundary conditions we will solve the diffusion equation in the field $0 < x < A$, $0 < y < B$, $-H < z < H$ (at the same time it is necessary to double the power of the model-based leak). Boundary conditions will be:

$$C_{x=0} = C_{x=A} = C_{y=0} = C_{y=B} = C_F; \quad \left.\frac{\partial C}{\partial Z}\right|_{z=\pm H} = 0,$$

where C_F is protective gas concentration of the irrigated surface.

Trial gas concentration in a sighting point is described by the equation:

$$C_{mnl} = \frac{8\sum_{i=1}^{k} Q_i \sin\left(\frac{m\pi x_i}{A}\right)\sin\left(\frac{n\pi y_i}{B}\right)}{D\cdot A\cdot B\cdot H\cdot \pi^2\left(\frac{m^2}{A^2}+\frac{n^2}{B^2}+\frac{l^2}{H^2}\right)}.$$

By the results of the hold research it is necessary to make a conclusion and to give practical recommendations as to the systems of leaks localization engineering realizing the group of gas-analytical methods by the probe with accumulative membranes:

- Accuracy in defining places of leaks and sensitivity to the revealed leaks can be raised by elimination of the influence of ambient air streams presenting on the control position;
- Possibility to fully eliminate ambient air affect on the concentration field of trial gas leak by disposing the membrane with open pores structure on the controllable surface;
- The thickness of membrane *H* and the diameter of the pores channel *D* should fulfill the inequality $H/D \geq 6$;
- Stable concentration field of trial gas leak permits to automate the process of defining places of leaks by the probe method;
- For the purpose of raising sensitivity and productivity of the test it is necessary to choose the membrane material with smaller porosity, but with the maximum tortuosity of the pores channel;
- Modelling the process of the analyzed sample transfer in the membrane it is lawful to choose the method of quasi-homogeneous approximation, and the process of trial gas transfer in the membrane can be restricted to the diffusion mechanism.