DOI 10.36622/VSTU.2021.49.1.005

UDC 621.6.036

A. L. Shurait¹, A. V. Birykov², A. P. Usachev³

**DEVELOPMENT OF A CALCULATION METHOD
FOR TWO-STAGE NATURAL GAS PURIFICATION PLANTS
FROM MECHANICAL IMPURITIES**

Giproniigaz PLC^{1,2}

Russia, Saratov

Yuri Gagarin State Technical University of Saratov³

Russia, Saratov

¹ *D. Sc. in Engineering, Prof., Director General, tel.: (8452)74-95-95, e-mail: shurait@niigaz.ru*

² *PhD, Director of the Research Center, tel.: (8452) 74-94-15, e-mail: Biryukov@niigaz.ru*

³ *D. Sc. in Engineering, Prof. of the Dept. of Heat and Gas Supply, Ventilation, Water Supply
and Applied Fluid Dynamics, tel.: (8452) 51-50-18, e-mail: usachev-ap@mail.ru*

Statement of the problem. Currently, there is no methodology for calculating the degree of clogging of a multilayer filter cartridge taking into account the prevention of deposition of mechanical impurities in the gap between the coarse and fine filter cylindrical filter cartridges. In this regard, the development of such a technique is an urgent task.

Results. In this paper, we propose a calculation method for determining the average integral degree of clogging of multilayer cylindrical filter cartridges with mechanical impurities and pressure loss on them which take into account the prevention of sedimentation of mechanical impurities in the gap between the coarse and fine filter cartridges.

Conclusions. The results obtained make it possible to determine the pressure loss and the average integral degree of clogging of the multilayer filter cartridge depending on the decrease in the living cross-section of all filter meshes in the process of clogging and to prevent the deposition of solids in the gap between the coarse and fine filter cartridges.

Keywords: calculation procedure, mechanical impurities, clearance, cylindrical filter cartridges, coarse and fine purification, natural gas, two-stage purification installation, prevention of deposition.

Introduction. Reliable operation of high-precision modern high-performance equipment for reducing the pressure of natural gas is achieved through the use of two-stage gas purification from mechanical impurities [11]. The analysis and experience of gas distribution organizations show that about 70 % of mechanical particles in their total balance are deposited on coarse cylindrical filter cartridges (CPF) and only 30 % — on fine CPF [2, 3, 6].

An example of a reduction line of the head gas reduction stations (GRS) with a total capacity of 500 thousand m^3/h with two-stage cylindrical setups (TCS) installed on it for coarse and fine purification of high throughput is shown in Fig. 1.

Fig. 1. TCS with coarse and fine purification capacity:

- 1, 4 are inlet and outlet branch pipes; 2, 3 are cylindrical filters with coarse and fine purification capacity;
5 is gas regulating equipment

The process of two-stage purification of natural gas from mechanical impurities was previously described in [1, 5—10, 14—21]. Thus, the principle of reducing capital and metal consumption, set forth in [9], is incorporated in the design of the TCS and involves placing in the internal volume of one housing coaxially installed CPFs of coarse purification from a single-layer mesh and fine purification from a multi-layer cloth located at the minimum permissible distance where the degree of clogging of the coarse filtering mesh does not increase compared to when the actual distance δ_{ph} between the filtering elements is $\delta_f > \delta_{min}$ (Fig. 2).

However, in [1, 5—10, 14—21] there is no method for calculating the degree of clogging of the CPF at any moment of operation considering the conditions that prevent the deposition of mechanical impurities in the gap between the CPF of coarse and fine purification. Therefore the development of such a calculation method is relevant.

Fig. 2. Diagram of a device with a coarse and fine purification CPF set up in the volume of one complex:

- 1 — vertical cylindrical body; 2, 6 — inlet and outlet branch pipes; 3, 4 — flange and filter cover; 5 — glass;
- 7, 8 — CPF for coarse and fine purification; 9 — cover for CFF 7 and 8;
- 10 — cells of CPF for coarse purification; 11 — the first in the direction of the gas flow filtering layers of the CPF of fine purification; 12 — gap between the CPF of coarse and fine purification;
- 13 — filtering layers of fine purification CPC following after the first ones;
- 14 — space for clean gas outlet area

The objective of the study is to develop a calculation method for identifying the degree of clogging of multilayer filter cloths of coarse and fine purification with mechanical impurities and the value of pressure losses on cylindrical filter cartridges.

1. Development of a calculation method for identifying the degree of clogging of coarse and fine filter purification.

In general, a multilayer filtering fabric is made of n nets, one after the other. The network gas with the maximum content of mechanical impurities at a constant design flow rate $V = \text{const}$ is cleaned in several meshes n (Fig. 3) sequentially performed along the gas flow, with square cells and a standard size equal to m_n . The mesh number n in the row will change in the range $n = 1; 2; 3; \dots, i$. The number of the standard size of the cells of each mesh n in a row in the process of clogging changes to the values $m_n = a_n, c_n, e_n, \dots, j_n$. In the process of clogging, mechanical impurities of a smaller size are deposited on each first mesh, thus each subsequent mesh in the direction of the gas flow has a smaller initial and subsequent sizes compared to the previous mesh.

Fig. 3. Scheme of successively located along the gas flow mesh fragments with a number in the range $n = 1; 2; 3; \dots, i$ and the standard size of the mesh cell equal to m_n :

$n = 1; 2; 3; \dots, i$ is the mesh number n in the row;

$m_n = a_n, c_n, e_n, j_n$ is the number of the standard size of the cells of each mesh n in a row during its clogging;

$L_{n=i, m=j_n=i}$ is the distance between two adjacent square cells of each next mesh n in the direction of gas flow in the process of clogging; $b_{n=i, m=j_n=i}$ is the width of square cells in the light of each next mesh n in the direction of gas flow in the process of clogging; $\Delta Z_{n=i, m=j_n=i}$ is the pressure loss when the gas passes through the mesh n in the direction of the gas flow during clogging

The distance between two adjacent square cells of each subsequent mesh $L_{n=i, m=j_n=i}$ in the direction of gas flow (Fig. 3) has a lower initial and subsequent value compared to the previous mesh $L_{n=i-1, m=j_{n=i-1}}$, i.e.,

$$L_{n=i-1, m=j_{n=i-1}} > L_{n=i, m=j_{n=i}}.$$

At the initial moment, the relative value of the net cross-section

$$b_{n=i, m=a_{n=i}}^2 / (b_{n=i, m=a_{n=i}} + L_{n=i, m=a_{n=i}})^2,$$

located at the point $n=i$ in the direction of the gas flow, corresponds to the degree of its clogging by mechanical impurities $\theta_{n=i, m=a_{n=i}}$ equals zero.

With $m=j$ as a contaminated element located at the point $n=i$ in the direction of gas flow (Fig. 3), a filter element with a cell having a smaller size is conventionally taken $b_{n=i, m=j_{n=i}}$

(at $m = j$) compared to the previous size $b_{n=i,m=(j-1)_{n=i}}$ (at $m = (j-1)_{n=i}$). A reduction of any previous size of the mesh cell located at point $n=i$ in the direction of the gas flow, with $b_{n=i,m=(j-1)_{n=i}}$ to the subsequent $b_{n=i,m=j_{n=i}}$ during its clogging is presented as an increase in the distance between the mesh cells to the value:

$$L_{n=i,m=j_{n=i}} = L_{n=i,m=a_{n=i}} + \sum_{m=1}^{m=j} (b_{n=i,m=(j-1)_{n=i}} - b_{n=i,m=j_{n=i}}). \quad (1)$$

The dependence for identifying the total pressure loss [12] when gas passes through a series of meshes $n=1; 2; 3; \dots, i$ sequentially located one after another (Fig. 3) along its course when each subsequent mesh n has a smaller initial and subsequent sizes compared to the previous one is written as:

$$\Delta Z_{n,m} = \sum_{n=1}^{n=i} \zeta_{n=i,m=j_{n=i}} \cdot \frac{V^2 \left[b_{n=i,m=a_{n=i}} + L_{n=i,m=a_{n=i}} + \sum_{m=1}^{m=j} (b_{n=i,m=(j-1)_{n=i}} - b_{n=i,m=j_{n=i}}) \right]^4}{b_{n=i,m=j_{n=i}}^4 \times F^2 \cdot 2 \cdot g} \cdot \rho_g, \quad (2)$$

where $\zeta_{n=i,m=j_{n=i}}$ is the coefficient of local resistance of the mesh [4] at the point $n = i$ in the direction of the gas flow for $m = j_{n=i}$ which is typical of the current size $b_{n=i,m=j_{n=i}}$, caused by its being polluted with mechanical impurities; V is the capacity of the filtering device at excess gas pressure at the inlet to the TCS numerically equal to the calculated gas flow rate [11], m^3/sec ; $b_{n=i,m=a_{n=i}}$ is the value of the nominal initial cell size of a clean mesh in the light, not contaminated with mechanical impurities which is located at the point $n=i$ in the direction of the gas flow for $m = a_{n=i}$ (Fig. 3), m ; $L_{n=i,m=j_{n=i}}$ is the value of the nominal initial distance between mesh cells in the light (Fig. 3) at the point $n=i$ in the direction of the gas flow for $m=j_{n=i}$, m ; $b_{n=i,m=(j-1)_{n=i}}, b_{n=i,m=j_{n=i}}$ is the previous and next dimensions of the square cell of the filtering mesh located at the point $n=i$ in the direction of the gas flow clogged with mechanical impurities, m ; ρ_g is the density of gas passing through the mesh cells at the excess pressure of the TCS inlet, kg/m^3 ; g is the value of the acceleration of gravity equal to $9,8 \text{ m}/\text{sec}^2$.

The average integral degree of clogging of the filter cloth (as a series of meshes) in fractions of one can be identified by means of calculating the total degree of clogging of all meshes and then dividing the resulting value by the number of meshes $n = i$:

$$\theta_{cp,n,m} = \sum_{n=1}^{n=i} \left\{ \frac{\frac{b_{n=i,m=a_{n=i}}^2}{(b_{n=i,m=a_{n=i}} + L_{n=i,m=a_{n=i}})^2} - \frac{b_{n=i,m=j_{n=i}}^2}{\left[b_{n=i,m=a_{n=i}} + L_{n=i,m=a_{n=i}} + \sum_{m=a_n}^{m=j_n} (b_{n=i,m=(j-1)_{n=i}} - b_{n=i,m=j_{n=i}}) \right]^2}}{\frac{b_{n=i,m=a_{n=i}}^2}{(b_{n=i,m=a_{n=i}} + L_{n=i,m=a_{n=i}})^2}} \right\} \quad (3)$$

$n=i$

Here, at any moment of operation with $m=j_{n=i}$, the relative value of the net cross section corresponds to a certain extent of its clogging by mechanical impurities. The formulas (2) and (3) are also valid for identifying the pressure loss and the mean integral degree of clogging of one filter mesh, e.g., as is the case for coarse CPF if the value $n=1$ is taken.

2. Development of a calculation method to prevent the deposition of solid particles in the gap between the CPF of coarse and fine purification. An integral part of the methodological provisions for identifying the degree of clogging of a multilayer filter cartridge is the development of conditions to prevent the deposition of mechanical impurities in the lower part of the gap 12 (Fig. 2) between the cylindrical filter cartridges of coarse and fine purification. In order to do this, the following ratio of the mesh sizes of coarse and fine CPF meshes was set forth (Fig. 2 and fragment A in Fig. 4):

1. Uncontaminated coarse filter element 7 made of woven metal mesh, which has 10 cells, with a nominal initial clear size $b_{rp,n=1,m=a_{n=1}}$ (Fig. 4), at the initial moment of operation passes through solid particles 15 with a maximum diameter d_u , equal to the size of the mesh $b_{rp,n=1,m=a_{n=1}}$ CPF 7 coarse purification. I.e.,

$$d_u = b_{rp,n=1,m=a_{n=1}} \quad (4)$$

2. An uncontaminated fine filter element 8 is made of a multi-layer fabric consisting of a number of meshes arranged one after the other, inside which solid particles will settle. In this case, at least the first layers 11 in the direction of the gas flow have cells with a size $b_{T,n=1,m=a_{n=1}}$ larger than the maximum diameter of solid particles d_u . I.e.,

$$b_{T,n=1,m=a_{n=1}} > d_u \quad (5)$$

The diameter of 11 fibers of these first uncontaminated layers $d_{T,n=1,m=a_{n=1}}$, laid one after the other, should be more than half the maximum diameter $d_u/2$ of solid particles 15, i.e.:

$$d_{T,n=1,m=a_{n=1}} > d_q / 2. \quad (6)$$

The thickness $S_{m,n=1,m=a_{n=1}}$ of the first two layers in the direction of gas flow exceeds the maximum diameter d_q of solid particles 15, i.e.:

$$S_{m,n=1,m=a_{n=1}} > d_q. \quad (7)$$

For each subsequent layer 13, the cell sizes are reduced, and the last layer has the minimum cell sizes. The operation of the CPF for coarse and fine purification, conducted according to the recommendations laid down in formulas (4)—(7), is performed in the following way.

Fig. 4. Diagram showing the aspect ratio at which the settling of solids is prevented in the lower part of the gap between the coarse and fine CPF, the capacity of the CPF is preserved. The geometric parameters of the meshes are shown on the enlarged lower part of the coarse and fine CPF. Positions 1—14 are the same as in Fig. 2; 15 is the maximum diameter of a solid particle

which passes through the mesh cells of the CPF coarse purification; 16 is the border between the gap 12 and the first in the direction of the gas flow filtering layers of the CPF of fine purification. At the first stage of operation, natural gas enters through the inlet pipe 2 (Fig. 2 and 4) and passes through the side surface of an uncontaminated coarse filter cartridge 7 made of woven metal mesh with a mesh size $b_{\text{rp},n=1,m=a_{n=1}}$. Large solid particles with a diameter of more than d_q , which are in the gas, settle on the outer surface of the rough CPF 7, and particles with a diameter $d_q = b_{\text{rp},n=1,m=a_{n=1}}$ or less pass through its cells. Further, the gas flows through the side filtering surface of the layers 11 of the fine cartridge 8, first in the direction of the gas flow, having cells with a size $b_{\text{T},n=1,m=a_{n=1}} > d_q$. Solid particles with a diameter $d_q = b_{\text{rp},n=1,m=a_{n=1}}$, equal to freely pass through the layers 11 of the fine cartridge 8, first in the direction of the gas flow, having cells of the size $b_{\text{T},n=1,m=a_{n=1}} > d_q$, and settle in their thickness. Since the fibers of the first layers 11 are made with a diameter $d_{m,n=1,m=a_{n=1}} > d_q / 2$, and their total thickness $S_{m,n=1,m=a_{n=1}} = 2 \cdot d_{m,1}$ will be greater than the diameter of particle 15, i.e., $S_{m,n=1,m=a_{n=1}} > d_q$ as shown in fragment A in Fig. 4, particles 15 will not protrude with their center of gravity beyond the boundary 16 of this layer and, as a result, fall into the lower part of the gap 12.

At the i -th stage of operation, in the process of clogging of the rough purification CPF 7, the size of the cells decreases, and only particles of diameter $d_{q,i}$ pass freely through them less than d_q , but no longer pass particles with a diameter equal to d_q . Further, particles with a diameter $d_{q,i}$ less than d_q are fed to the first layers 11 of the fine cartridge 8 in the direction of the gas flow. Then the gas passes through the side filtering surface of the first in the direction of gas flow layers 11 of the cartridge 8 of fine purification, having a cell size $b_{\text{T},n=i,m=a_{n=i}} > d_{q,i}$. Solid particles with a diameter $b_{\text{T},n=i,m=a_{n=i}} > d_{q,i}$ freely pass through the cells of the layers 11 of the fine cartridge 8, first in the direction of the gas flow, and settle in their thickness.

Given that according to [3, 6], the fine CPF clog up several times slower than the coarse CPF, the diameter of solid particles at the i -th stage of the operation will always be less than the cells, the first layers 11 of the fine filter cartridge 8 in the direction of gas flow, i.e., $b_{\text{T},n=i,m=a_{n=i}} > d_{q,i}$. Hence in the gap 12 between the CPF of coarse and fine purification at any stage of the operation, a continuous layer of particles does not form, clogging the cells of its lower part, as a result of which the throughput of the CPF does not decrease. According to the results of this proposal,

a positive decision was received on the grant of a patent on 02/04/2020 on application No. 2019132265 with a priority from 10/11/2019.

In order to test the possibility of eliminating the settling of solid particles in the lower part of the gap 12 between the CPC of coarse 7 and fine 8 purification (Fig. 2) and maintaining the capacity, the TCS was manufactured and then tested in the experimental center of JSC “Gipronigaz” (Saratov) with a diameter of $D = 160$ mm with a coarse-purification CPFC based on a high-precision metal mesh with a square cell of 0.2 mm in compliance with GOST 6613-86. For testing, air with sand particles of 0.25 in size was employed as a working medium; 0.22; 0.2; 0.1; 0.05 mm. In this case, the proportion of fractions with sizes over 0.2 mm was 70 % in the total mass of impurities, and the proportion of fractions with sizes equal to 0.2 mm or less was 30.0 % [3].

Fine filter cartridges with a minimum cell size of the last layer of 0.04 mm in the direction of gas flow were made in two versions.

First option. The filtering cloth of the cartridge is made on the basis of a high-precision mesh with the number of layers equal to seven in accordance with GOST 6613-86. The mesh number in the row n , the size of the square cells $b_{T,n=1,m=a_{n=1}}$, the wire diameters $d_{m,n=1,m=a_{n=1}}$ of the fine-cleaned CPF for option 1 are presented in Table. 1. At least the first two layers 11 in the direction of gas flow have cells sized $b_{T,n=1,m=a_{n=1}} > b_{rp,n=1,m=a_{n=1}}$, i.e., $0.22 > 0.2$ mm. Solid particles with a maximum size equal to $d_q = b_{rp,n=1,m=a_{n=1}}$, i.e., $d_q = 0.2$ mm passing from the coarse filter cartridge freely pass through the first two layers 11 in the direction of the gas flow of the fine cylindrical element 8, have cells sized $b_{T,n=1,m=a_{n=1}} > d_q$. The metal wires of the meshes of the first two layers 11 are made with a diameter $d_{m,n=1,m=a_{n=1}}$ more than half of the maximum diameter $d_q/2$ of the solid particles 15, i.e., $d_{T,n=1,m=a_{n=1}} > d_q / 2$.

Table 1

The mesh number in the row n , the size of the square cells and the wire diameters dt .
for CPF fine purification according to option 1

Mesh number, n	1	2	3	4	5	6	7
Cell size, $b_{T,n=1,m=a_{n=1}}$, mm	0.22	0.22	0.18	0.14	0.1	0.071	0.04
Wire diameter, $d_{m,n=1,m=a_{n=1}}$, mm	0.12	0.12	0.12	0.09	0.06	0.05	0.03

Then the layer thickness of the first two metal wires $S_{m,n=1,m=a_n=1} = 2d_{T,n=1,m=a_n=1}$ will be larger than the particle diameter 15, i.e., $S_{m,n=1,m=a_n=1} > d_q$ or $0.24 > 0.2$ mm. As the thickness $S_{m,n=1,m=a_n=1}$ exceeds the maximum diameter d_q of a solid particle 15, i.e., $S_{m,n=1,m=a_n=1} > d_q$, as shown in section A in Fig. 4, it does not project its center of gravity beyond the boundary 16 of this layer and, as a result, does not fall into the lower part of the gap 12.

Second option. The filtering cloth of the cartridge 8 is made on the basis of a high-precision mesh with the number of layers equal to seven in compliance with GOST 6613-86.

Mesh number in a row n , sizes of square cells $d_{m,n=1,m=a_n=1}$, the wire diameters $d_{T,n=1,m=a_n=1}$ for CPF of fine purification for option 2 are presented in Table 2. In this case, the first layers 11 in the direction of the gas flow have cells sized $b_{T,n=1,m=a_n=1} < b_{rp,n=1,m=a_n=1}$, i.e., $0.14 < 0.2$. Solid particles with a maximum size $d_q = b_{rp,n=1,m=a_n=1}$ exceed the diameter of the first two layers in the direction of gas flow $d_q > d_{m,n=1,m=a_n=1}$, i.e., $0.2 > 0.09$ mm. The metal wires of the meshes of the first two layers 11 have a diameter $d_{m,n=1,m=a_n=1}$, less than half the maximum diameter $d_q/2$ of the solid particles $d_{m,n=1,m=a_n=1} < d_q / 2$, i.e., $0.09 < 0.1$ mm. Then the layer thickness of the first two fibers $S_{m,n=1,m=a_n=1} = 2d_{m,n=1,m=a_n=1}$, will be less than the maximum particle diameter 15, $S_{m,n=1,m=a_n=1} < d_q$, i.e., $0.18 < 0.2$ mm. Since the thickness $S_{m,n=1,m=a_n=1}$ does not exceed the maximum diameter d_q of the solid particle 15, i.e., $S_{m,n=1,m=a_n=1} < 0.2$ mm, it projects its center of gravity beyond the boundary 16 of this layer and, as a result, falls into the lower part of the gap 12.

Table 2

Mesh number in a row, square mesh sizes and wire diameters
for CPF fine purification according to option 2

Mesh number, n	1	2	3	4	5	6	7
Cell size, $b_{T,n=1,m=a_n=1}$, mm	0.14	0.14	0.12	0.1	0.071	0.05	0.04
Wire diameter, $d_{m,n=1,m=a_n=1}$, mm	0.09	0.09	0.08	0.06	0.05	0.036	0.03

The test results showed the following. For the first option, the presence of individual solid particles in the lower part of the gap 12 between the coarse and fine CPF without the formation of a continuous layer clogging the cells of the lower part of the coarse and fine CPF was noted.

For the second variant, the formation of a continuous layer with a height 23.0 mm, clogging the lower part of the gap 12 between coarse and fine CPCs and reducing their capacity.

Therefore the suggested ratio of the sizes of this methodological position:

$$d_q = b_{rp, n=1, m=a_{n=1}}; b_{T, n=1, m=a_{n=1}} > d_q; d_{T, n=1, m=a_{n=1}} > d_q / 2; S_{m, n=1, m=a_{n=1}} > d_q. \quad (8)$$

This ratio prevents the accumulation of solid particles in the lower part of the gap between the coarse and fine CPF.

Conclusions

1. A calculation method has been developed that for the first time has allowed the representation of filtering cloth clogging as a change in a row of n sequentially arranged meshes in the course of a gas flow with square cells with the m -th standard size. In this case, each subsequent grid n in the direction of the gas flow has smaller initial and subsequent dimensions compared the previous mesh. In the suggested calculation method, conditions are implemented to prevent the deposition of solid particles in the lower part of the gap between the coarse and fine CPFs by including a number of ratios of the mesh sizes of the coarse and fine CPF meshes.

2. The expressions (2) and (3) were obtained to identify the value of the pressure loss on the filter cartridge and the mean integral value of the degree of clogging of the CPF depending on the value of the decrease in the free cross-section of all filter nets during clogging.

3. The formulas (4)—(7) are set forth for identifying the ratio of the mesh sizes of coarse and fine CPF grids allowing the prevention of the deposition of solid particles in the lower part of the gap between the coarse and fine CPF and maintaining their capacity.

References

1. Belousov V. V. *Teoreticheskie osnovy protsessov gazoочistki* [Theoretical foundations of gas purification processes]. Moscow, Metallurgiya Publ., 1988. 256 p.
2. Birger M. I., Val'dberg A. Yu., Myagkov B. I. *Spravochnik po pyle- i zoloulavlivaniyu* [Handbook of dust and ash collection]. Moscow, Energoatomizdat Publ., 1983. 312 p.
3. Gustov S. V. *Istochniki vznikeniya i razmery vzveshennykh v prirodnom gaze tverdykh chastits* [Sources of origin and sizes of particulate matter suspended in natural gas]. *Nefegazovoe delo*, 2011, no. 4, vol. 9, pp. 98—101.

4. Idel'chik I. E. *Spravochnik po gidravlicheskim soprotivleniyam* [Handbook of hydraulic resistance]. Moscow, Mashinostroenie Publ., 1975. 559 p.
5. Karyakin E. A. *Promyshlennoe gazovoe oborudovanie: spravochnik* [Industrial gas equipment: a directory]. Saratov, Gazovik Publ., 2013. 1125 p.
6. Kouzov P. A., Mal'gin A. D., Skryabin G. M. *Ochistka gazov i vozdukha v khimicheskoi promyshlennosti* [Purification of gases and air in the chemical industry]. Saint-Petersburg, Khimiya Publ., 1993. 320 p.
7. Mazus M. G., Mal'gin A. D., Morgulis M. L. *Fil'try dlya ulavlivaniya promyshlennykh pylei* [Filters for trapping industrial dust]. Moscow, Mashinostroenie Publ., 1985. 240 p.
8. Usachev A. P., Shuraits A. L., Rulev A. V., Salin D. V., Usuev Z. M. *Ustroistvo po predotvrashcheniyu rasprostraneniya oblomkov za predely fil'truyushchego elementa prirodnogo gaza* [Device for preventing the spread of debris beyond the filter element of natural gas]. Patent PF, 2016, no. 2016116727/05.
9. Shuraits A. L., Usachev A. P., Salin D. V., Khomutov A. O., Usuev Z. M. *Ustroistvo dlya ochistki ot tverdykh chastits prirodnogo gaza vysokogo davleniya* [A device for purification solid particles of natural gas of high pressure]. Patent PF, 2017, no. 2017111708.
10. Straus V. *Promyshlennaya ochistka gazov: per. s angl.* [Promyshlennaya ochistka gazov]. Moscow, Khimiya Publ., 1981. 616 p.
11. Usachev A. P. e.a. *Teoreticheskie i prikladnye osnovy povysheniya effektivnosti i bezopasnosti ekspluatatsii ustanovok gruboi ochistki prirodnogo gaza ot tverdykh chastits v sistemakh gazoraspredeleniya: monografiya* [Theoretical and applied fundamentals of increasing the efficiency and safety of operation of coarse purification of natural gas from solid particles in gas distribution systems]. Saratov, Sarat. gos. tekhn. un-t Publ., 2013. 172 s.
12. Chugaev R. R. *Gidravlika*. Uchebnik dlya vuzov. Izdan-e 4-e dop. i pererab. [Hydraulics. Textbook for high schools]. Leningrad, Energoizdat. Leningr. otd-nie, 1982. 672 p.
13. Shur I. A. *Gazoregulyatornye punkty i ustanovki* [Gas control points and installations]. Leningrad, Nedra Publ., 1985. 288 p.
14. Guo B., Ghalambor A. *Natural Gas Engineering Handbook*. 2nd edition. Houston, Texas, Gulf Publishing Company, 2012. XX. 472 p.
15. Hutten I. M. *Handbook of Nonwoven Filter Media* 2nd Edition. Butterworth Heinemann, 2016. 660 p.
16. Mokhatab S., Poe W. A. *Handbook of Natural Gas Transmission and Processing*. Second Edition. Elsevier Inc., 2012. 802 p.
17. Sutherland K. *Filters and Filtration Handbook*. 5 edition. Elsevier Science, 2008. 523 p.
18. Thomas D., Charvet A., Bardin-Monnier N., Appert-Collin J.-C. *Aerosol Filtration*. ISTE Press – Elsevier, 2016. 218 p.
19. Tien Ch. *Principles of Filtration*. Elsevier, Oxford, 2013. 360 p.
20. Trevor S. *Filters and Filtration Handbook*. 5 edition. Elsevier Butterworth Heinemann, 2016. 444 p.
21. Wang X., Economides M. *Advanced Natural Gas Engineering*. Gulf Publishing Company, 2013. 400 p.