Methodological Guidelines for Prevention of Destruction of Parallel Filter Cartridges Located in One Vessel at Maximum Pressure Drop

A P Usachev, A L Shurayts, A V Biriukov

1 Gagarin Saratov State Technical University, 77 Politechnicheskaya street, 410054 Saratov, Russia
2 Joint-Stock Company “Giproniigaz”, 54 Prospekt Kirova, 410012 Saratov, Russia

E-mail: ritamitrofanova@yandex.ru

Abstract. Technical literature lacks scientific foundations for prevention of destruction of parallel filter cartridges within one vessel in gas purification devices at maximum pressure drop. In order to prevent filter net damage caused by solid particles, which can be found in the raw (non-purified) gas stream at the inlet to the gas purification device, we have developed principles and technical solutions for installation of a protective plate with perforated holes, the size of which excludes entry of debris capable of destroying the outer surface of the filter net. In order to prevent the destruction of fully-clogged filter net from the impact occurring as the result of pressure drop in the filter cartridge, we have developed solutions for transferring gas pressure from the clogged net to the supporting rectangular plate perforated with openings. An equation is proposed for finding the maximum opening diameter in rectangular support plates, which prevent damage to the clogged filter mats adjacent to them in the event of an increase in the pressure drop to the maximum value in the cartridge.

1. Introduction

Harsh Russian climate conditions high demand for natural gas [1] and, consequently, a demand for high-capacity gas reducing stations (GRS) [2-4], designed according to [5-7], which supply the gas supply network of residential areas, industrial consumers, and enterprises of the power generating complex with fuel.

Due to this fact, the scale of using modern high-capacity gas reducing stations is growing nowadays, for example, 500 and 250 thousand m³/hour in the Russian city of Ufa, 200 thousand m³/hour in Voronezh, 500 and 250 thousand m³/hour in Volgograd, as well as in a number of other localities equipped with high-precision gas regulating equipment. In Sterlitamak (the Republic of Bashkortostan) preparations are being made for the installation of the main GRS with the capacity of about 700,000 m³/h.

Modern high-capacity gas equipment requires the use of gas purification devices (GPD) of similarly high efficiency, which can provide a high level of reliability and safety.
2. Relevance and design principles for parallel filter cartridges that are connected within one vessel and protected from the effects of large solid particles and the maximum pressure drop

Gas purification devices, which are produced now and located in front of the major gas reducing stations, have insufficient capacity, low level of reliability and safety, high frequency of operations for the regeneration of filter cartridges (FC) and, consequently, high operating costs [8-10].

In order to eliminate these disadvantages, new principles and provisions have been developed to increase the throughput capacity of the GPD with a minimum number of regenerations (Fig. 1) due to the arrangement of a series of parallel-connected filter cartridges with pleated net within the volume of one vessel. In this case, each of them contains chambers for clogged gas and purified gas, formed by filtering 8 and solid 12 plates (Fig. 1). For the proposed GPD design, it is possible to increase the throughput by increasing the number of FCs without technical re-equipment of the GRS, which is associated with the replacement of the station with a more productive size-related type. The proposed construction is protected by patent RU No. 131989U1 [11]. The arrows on the lines in Fig. 1 show the direction of the gas flow. The red and blue color of the lines indicates, respectively, that gas is not purified and cleared of impurities.

![Diagram of GPD](image)

1,4– inlet and outlet connectors with distribution gas pipelines at the inlet and outlet of the GPD; 2 and 3 – first and second clamping covers with holes along their sides for threaded studs 15; 5 – perforated bumper plate; 6 – a row of round openings in the perforated bumper plate 5; 7 – a row of round openings in the plates 8; 8 – one of the rows of filter plates; 9 – filter cartridge made of flat metal net; 10 – inlet opening in every filter plate 8; 11 – sealing gasket between plates 8 and 12, and between cover 2 and plate 5, cover 3 and plate 8; 12 – solid plate; 13 – inlet openings in every plate 12 for purified and non-purified gas; 14 – sealing ring between openings 10 and 13; 15 – threaded studs with washers and screws; 20 – upper and lower guide rods for moving and fixing cover 2 and plates 5, 8 and 12; 16 – liner and locking pin for moving along the upper rod 20 of cover 2; 17 – pipe insert dismantled for cover expansion 2, plates 5, 8 and 12; 18, 19 – support stand and bolts for connecting upper and lower guide rods 20; m, n – width and height of the rectangular support plate along its pinching lines, mm.

**Figure 1.** GPD, containing a row of parallel filter cartridges interconnected within one vessel and protected from the impact of large solid particles and maximum pressure drop.

One of the major tasks that need to be solved in designing and developing the proposed GPD is the prevention of filter cartridges destruction.

If fragments of the destroyed equipment installed before the gas purification device along the course of the gas flow, there is danger of filtering nets destruction 9. To prevent this destruction, the present work proposes technical solutions for installing a protective plate 5 perforated with holes 6 with the diameter that excludes entry of debris capable of damaging or destroying the outer surface of the net 9.
Secondly, the danger of filter net 9 destruction appears at maximum pressure drop at the FC. In order to prevent the completely clogged filter net 9 from being destroyed due to the pressure drop that occurs at the FC, solutions have been developed to shift the force from gas pressure on the clogged net 9 to the support plate 8. In order to do this, the plate 8 is made of a single sheet with round openings 7, the size of which excludes the destruction of the plate 8 and the clogged net 9 pressed against it by the gas pressure drop. In the existing GPD design there is one rectangular opening for gas passageway in the support plate 8, and the filtering net is fixed along its edges. In this case, the support plate 8 with one rectangular opening did not withstand the effect of the maximum gas pressure drop on the net 9 and was deformed, which broke the hermeticity of its joints.

The proposed gas purification device, equipped with perforated bumper plate 5 and a number of support plates 8 with evenly distributed openings 7, operates as follows. At first, raw gas (red lines in Fig. 1) with solid particles before entering GPD passes through openings 6 in the protective bumper plate 5. The diameter of the openings 6 prevents large solid inclusions from penetrating or destroying the net 9 from its outer surface. Then part of the raw gas without large solid particles enters the first filter net 9 alongside the gas flow, which is fixed to the filter plate 8, where it is cleaned of impurities. The remaining raw gas after the bumper plate 5 runs through the opening 10 in the first downstream gas filter plate 8, the sealing ring 14, and the opening 13 in the solid plate 12, then it passes into the series of middle parallel chambers that are formed alongside the gas flow by solid plates 12, sealing gaskets 11 and filter plates 8. From here, the raw gas flows in equal parts into the series of filter nets 9 fixed on the filter plates 8, where it is cleaned of impurities.

Purified gas that has been purified in such manner, flows through the openings 7 in the filter plates 8, passes through the series of middle parallel chambers that are formed in the gas flow direction by the filter plates 8, sealing gaskets 11 and solid plates 12. The sealing rings 14 prevent the raw gas from entering the chambers with gas, which is free from impurities, and which is formed by filter plates 8, sealing rings 11 and solid plates 12.

Purified gas goes through the openings 13 in the middle of solid plates 12, sealing gaskets 14 and openings 10 in the middle filter plates 8, and then goes to the last downstream chamber formed by the filter plate 8, sealing gasket 11 and cover 3 where it is mixed with a part of gas, that has been purified in the last filter net 9 along the course of the gas flow. From there, gas enters the outlet 4 and then goes into the distribution gas pipeline connected to it. In the event of maximum pressure drop in the FC, the clogged nets 9 are pressed against filter plates 8 and gas pressure force is transferred to them.

Utilization of the proposed gas purification devices allows: 1) to increase the efficiency of the GPD due to the compact arrangement of the filtering surface in the volume unit of its vessel; 2) to perform flexible increase of the filtering surface of the GPD by installing middle purification units in them; 3) to reduce the costs on cleaning the device from contamination by increasing the total area of the FC and, consequently, by reducing the number of cleaning operations of the GPD; 4) to reduce the area of the premises allocated for the device, as well as to reduce the cost of its heating.

The experience of design and operation, as well as the analysis that has been carried out, show that the rectangular shape is the most suitable shape for filter plates 8, since in this case the maximum filtering area of the nets 9 is reached.

3. Problem setting and development of methodological guidelines for prevention of destruction of parallel filter cartridges located in one vessel at maximum pressure drop
An important task related to the possibility of using support filter plates 9 is to ensure their strength and stability from the outer side under increasing pressure drop to a limit above which destruction occurs. V.V. Gorev, I.I. Krylov, [12] and G.S. Vedenikov [13], V.V. Biryulyova [14], D.V. Weinberg [15], V.V. Kuznetsov [16] and other researchers in their works tried to solve certain scientific problems of ensuring the strength of supporting plates loaded by a uniform load from the outer surface. In their work A.P. Usachev, A.L. Shurayts, and S.V. Gustov [17] made an attempt to determine the diameter of the opening of the cylindrical shell loaded by pressure drop, at which the necessary strength is achieved. However, the above equations are valid only for cylindrical support
shells and are not applicable for the calculation of flat plates, which require the development of acceptable solutions. In addition, presence of a rectangular shape of the support plate also requires individual consideration.

The problem setting looks as follows: under normal operating conditions, the filter net 2, which is not clogged with mechanical impurities, has a structural gap against the support plate 1, which allows to purify gas by the entire filtering surface of the metal net 9. Under the influence of the maximum pressure drop $\Delta P_{\text{max},t}$ before and after the filter net 2 at the time of complete clogging with mechanical impurities, it is firmly pressed against the rectangular support plate 1 with round openings 3 for gas flow, evenly distributed over its surface. The scheme of the rectangular perforated support plate 1 and the clogged net 2 pressed against it is shown in Fig. 2.

The clogged filter net 2, which is tightly pressed against plate 1 with width $m$ and height $n$, completely transfers the load from the effect of the maximum pressure drop on the plate. To strengthen the openings 3 and take into account the rectangular shape, which significantly weaken the strength of the plate 1, compared to a solid plate in the form of a cylinder, its actual thickness $S_{p,e}$ is taken with an excess and increases to a value at which it is able to withstand the effect of the pressure drop $\Delta P_{\text{max},t}$ before and after it. The ultimate goal is to determine the maximum value of the diameter of the openings $d_{p,i}$ of the support plate 1, at which it can withstand the maximum pressure drop $d_{p,i}$ before and after it.

1- rectangular supporting perforated plate; 2 – filter net; 3 – round openings in support plate 1 for gas passage; 4 – sealing gasket, the perimeter of which is the pinching line of the rectangular support plate by the clamping caps of the GPD vessel; 5 – sealing ring for the opening; 6 – opening for passage of a part of purified gas in the support flat plate 1; $m$, $n$ – width and height of the rectangular supporting plate along its pinching line, mm; $b_p$ – clear distance between neighbouring openings 3, mm.

**Figure 2.** The design scheme of a rectangular supporting perforated plate with a filter net densely pressed against it.

In order to obtain an acceptable solution, studies were carried out which, according to the requirements of [18-20], obtained the equation (1) for determining the diameter of the openings $d_{p,i}$ in the rectangular support plate 1, at which it withstands the impact of the maximum pressure drop $\Delta P_{\text{max},t}$ before and after it. The diameter of the openings $d_{p,i}$ found from the equation (1) is carried out using the method of selection for a number of values of the actual thickness of the flat support plate $S_{p,e}$ and is determined from condition [18, 19] with consideration of [20]:

![Diagram](image-url)
where \( S_{p,e} \) is the factual excess thickness of the supporting rectangular perforated plate, mm; \( C_p \) is the value of the total correction to the thickness of the supporting steel plate due to the influence of manufacturing technology, erosion and corrosion, minus tolerance for the thickness of thin steel plate, mm; \( d_{n,i} \) is the diameter of \( i \)-th opening in the support plate, mm; \( m \) is the distance along the pinching lines of the smaller side of the rectangular support plate (Fig. 2), mm; \( K_p \) is the coefficient depending on the design peculiarities of the flat plate; \( Y \) is the coefficient, which takes into account the ratio of the sides of the support plate of rectangular shape \([20]\); \( \Delta P_{\max} \) is the maximum theoretical differential pressure applied to the support plate, MPa; \( [\sigma_p] \) is the permissible stress of the material (stainless steel) from which the flat support plate of the filter cartridge is made at the design temperature, MPa.

The coefficient taking into account the ratio of the sides of the plate of the rectangular form \( Y \) is determined, according to [20], by the formula:

\[
Y = 1.41 / \sqrt{1 + \left( \frac{m}{n} \right)^2},
\]  

where \( n \) is the distance along the pinching lines of the larger side of the rectangular support plate (Fig. 2), mm.

Calculating the diameter of the openings in the support plate 1, according to equation (1), depending on its geometric and structural parameters, is as follows. Round openings 3 with diameter \( d_{p,i} \) in steel plate 1 (Fig. 2), have a corridor arrangement, and will be taken as openings that have not been additionally strengthened.

Let us assume that in equation (1) there is an actual excess thickness \( S_{p,e} \) of plate 1 (Fig. 2), in comparison with a plate without openings, due to the fact that in its design there is no additional strengthening of the openings. Strengthening of openings is done by installing cover plates around them \([18, 19]\). This technical solution is not acceptable due to the tight arrangement of the holes. The numerical complex can be seen in formula (1):

\[
\sqrt{\left[ 1 - \sum \left( \frac{d_{p,i}}{m} \right)^3 \right] / \left[ 1 - \sum \left( \frac{d_{p,i}}{m} \right) \right]} \cdot \frac{S_{p,e} - C_p}{m} - m.
\]  

It characterizes the reduction of support plate 1 strength due to presence of openings with diameter \( d_{n,i} \).

An example of finding the diameter of holes in a supporting steel plate. In formula (1) we set the value of its actual thickness sized \( S_{p,e} = 0.5 \text{mm} \). For given actual thickness of the supporting steel plate \( S_{p,e} = 0.5 \text{mm} \), we specify a number of values of the diameters of its openings \( d_{p,i} \) in formula (1) and, using the method of successive approximations, we reach the equality of its right and left parts. At the final step of the approximation, we put the diameter of the opening \( d_{p,i} = 6.0 \text{mm} \) into the formula (1). For the diameter of the plate \( d_{p,i} = 6.0 \text{mm} \) with a distance between adjacent openings \( b_p = 5 \text{mm} \) and values \( m = 270, n = 690 \text{mm} \), we calculate the number of openings for the largest section, which is:

\[
z_p = n / (d_{p,i} + b_p) = 270 / (6 + 5) = 24 \text{ openings}
\]

For the obtained value \( z_p = 24 \text{ openings} \), based on the formula (3) we find a numerical complex for weakening the openings in the support plate and put it in the identical equation (1). If at values \( z_p \) and calculation results based on formula (3) the left and the right parts of the identical equation (1) are not equal, we take another value of the opening’s diameter \( d_{p,i} \). Sequential approximation is performed until we obtain satisfactory convergence of the right and left parts of the identical equation (1) at 0.2%.

As a result of the calculations, the convergence of the right and left parts of formula (1) with an error of 0.2% is ensured, when the diameter of the plate equals \( d_{p,i} = 7.0 \text{mm} \).
Thus, the diameter of the openings in the steel support plate, at which the design strength is provided, is taken equal to $d_{op}=7.0 \text{ mm}$.

2.6 For the purpose of experimental verification of the calculation equation correctness (1), gas purification device was made and tested at the research and production center of “Gipronigas” JSC, which contained a number of parallel FCs made of net with cell size of 0.08 mm, located in the same vessel and protected from the influence of large solid particles and the maximum pressure drop. When carrying out strength tests, the filtering surface located on the support plate was closed with a thin gas-tight film. The film in this case imitated a net that was completely clogged with solid particles.

The results of the experiments show that the proposed design of the support plate at $m=270$, $n=690$ mm, actual excess wall thickness $S_{pc}=0.5 \text{ mm}$ with round openings $d_{op}=7.0 \text{ mm}$ in diameter, has withstood the stability and strength test and retained its shape under maximum pressure drop $\Delta P_{max, exp}=20 \text{ kPa}$, when it was applied to it. From the graph it follows that the deflection of the rectangular support plates of all the test specimens has occurred within the range of pressure drops $\Delta P_{max, exp}=23.5-26 \text{ kPa}$ (is the maximum experimental differential pressure), which is higher than the theoretical value of the maximum differential pressure on the cartridge, adopted in equation (1), i.e. $\Delta P_{max}=20 \text{ kPa}$. The obtained average deviation of theoretical values from experimental values is 23.7%, which allows us to recommend the equation (1) for use in engineering practice.

Based on the result of the tests, it has been established that the diameter of the openings of the bumper plate 5, at which the filter nets are not damaged by large solid particles from the outer side, is 2.0 mm.

4. Conclusion
1. We have developed technical solutions for installation of a protective bumper plate, perforated with holes, the diameter of which prevents large solid particles from destroying the outer surface of the filter net.
2. We have proposed the principle of maximum pressure drop force transfer from a completely clogged net to a supporting filter plate, which has round openings for gas passage, with the diameter that excludes the destruction of a clogged net pressed against it.
3. We have proposed an equation for finding the maximum value of the openings’ diameter in rectangular support plates, which prevents the destruction of clogged filtering nets that are pressed against them when maximum pressure drop occurs in the FC. The proposed equation makes it possible to take into account strengthening of the openings by exceeding the actual thickness of the plate wall above the theoretically necessary thickness, distance between the openings, and shape of the plate.

5. References
[1] GOST 5542-2014 2015 Natual fuel gases for commercial and domestic use Technical specifications (Moscow: Standartinform) p 51
[2] Shurayts A L, Usachev A P and Gustov S V 2010 High-tech gas distribution units – the road to increasing reliability of the gas distribution networks Russian Gas 41 56-60
[3] Industrial gas equipment 2013 Reference Book (Saratov: Gazovik) ed 6 p 1125
[4] Usachev A P, Usachev A P and Gustov S V 2013 Theoretical and applied principles of increasing the efficiency and safety of operation of natural gas coarse treatment units from solid particles in gas distribution systems Monograph ( Saratov: Saratov state technical university) p 172
[5] GOST 34011-2016 2017 Gas distribution systems Gas pressure regulating and metering stations Gas reducing stations General technical requirements Interstate standard (Moscow: Standartinform) p 17
[6] Shurayts A L, Volkov V S and Udovenko V E 2003 General provisions for the design and construction of gas distribution systems made of metal and polyethylene pipes Handbook of rules 42-101-2003 (Moscow: State Unitary Enterprise "Center for Design Products in Construction") p 168
[7] Habdbook of rules 62.13330.2011 2010 Gas distribution systems Updated version of SNiP 42-01-2002 (Moscow: Minregion of Russia) p 66
[8] Shur I A 1985 Gas regulation units and installations (Leningrad: Nedra) p 288
[9] Ionin A A 2012 Gas supply (Moscow: Lan’) p 438
[10] Staskevich N L, Severinets G N and Wigdorczyk D Ya 1990 Reference book on gas supply and use of gas (Leningrad: Nedra) p 762
[11] Usachev A P Shurayts A L and Biryukov A V 2013 Multi-unit plant for cleaning natural gas from mechanical impurities Patent RU No 131989U1 Bul No 25
[12] Gorev V V 2002 Metal constructions Volume 2 Construction of buildings (Moscow: Higher School) p 528
[13] Vedenikov G S 1998 Metal constructions General course (Moscow: Stroyizdat) p 760
[14] Biryulova V V 1990 Design of metal constructions: Special course (Leningrad: Stroyizdat) p 432
[15] Weinberg D V 1973 Handbook of Strength, Stability and Oscillations of Plates (Kiev: Budivelnik) p 488
[16] Kuznetsova V V 1998 Metal constructions Designer’s directory in 3 volumes (Moscow: Publishing House ACD) p 576, p 512, p 512
[17] Shurayts A L, Usachev A P and Gustov S V 2012 Development of the objective function establishing the requirements for preventing the destruction of filter elements in natural gas purification plants Oil and Gas Industry (Electronic Scientific Journal) 6 360-375
[18] GOST P 52857.2-2007 2008 Vessels and plant equipment, column type vessels strength calculation standards and methods (Moscow: Standartinform) p 58
[19] GOST 14249-89 2003 Vessels and devices Norms and methods of strength calculation methods Interstate standard (Moscow: IPK Izdatelstvo standartov) p 69
[20] Engineering documentation 10-249-98 Norms for calculating strength of stationary boilers and steam and hot water pipelines 1999 Approved by the Decree of the Gosgortekhnadzor of Russia (Moscow: No. 50 of 25.08.1998) p 245