Selection the rational option of the gas supply system

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Abstract. An important reserve for decreasing the consumption of materials of gas pipelines is to increase the operating pressure in the gas distribution system. The introduction of the practice of design of the gas supply system with household stabilizers of pressure requires developments of scientific methods of calculation and design. The annual saving of fuel gas due to the pressure stabilization according to experimental research of the authors is 2÷3 %. Installation of house regulators gas pressure also ensures saving of fuel gas. In the presence of stabilizers, gas plants operate at a gas pressure close to nominal, at maximum efficiency. The results of the study allow us to conclude about the effectiveness of the use of networks of medium pressure gas with the subsequent reduction to the desired values brownies pressure controllers or regulators-stabilizers. The article contains the results of studies of the thermal efficiency of equipment, that operating on gas fuel. There are an algorithm for determining the relative efficiency and the results of experimental studies of household gas appliances for assessing their thermal efficiency.

Introduction

In the modern sense the gas complex of Russia dates back to the mid-1950s. During this period, stationary points for reducing gas were the main points of support, its production required to build a full-fledged building, which predetermined high degree of centralization and the suitable structure of the distribution gas pipelines. This type of reduction points was reliable, easy to operate, however, their construction required a lot of time and money. At present, stationary gas control points do not conform to existing requirements of construction and become outdated. One of the main elements of gas supply systems is gas pipelines, over half of all capital investments were spent on their construction, while about 2/3 of the length of gas networks was required for low-pressure gas pipelines [1, 2]. This circumstance caused the increased metal consumption (material consumption) of the system, which entailed an increase in the constructional cost and operation of gas supply systems.

The further development of village gas supply systems is connected with the extensive use of gas storage units, the mass production of which was assimilated by native industry in the 70s of the last century.

The low cost of gas storage units in combination with a wide range of capacity qualitatively changes the structure of gas distribution systems. The presence of a large number of inexpensive reduction points in the village sharply reduces the length, material and capital intensity of low-pressure gas networks. Despite the increased length of gas networks of high (medium) pressure, mentioned circumstance causes a significant reduction in a total costs for the construction and operation of village gas supply systems.

An important reserve for improving the economic efficiency of gas distribution networks is the use of single-stage gas supply systems. In this case, gas supplied to consumers through high-pressure (medium) gas pipelines. Reduction of the gas pressure before the supply to the building made by gas
storage units of reduction equipped with house pressure regulators. At present, such designs are serially produced by various enterprises. The capacity of the gas pressure regulators used in them is 6 and 10 m³/h, which completely covers the demand for gas of individual apartment houses of the manor (cottage) type. The indicated reduction points with house pressure regulators are simple and reliable in operation, have a low manufacturing cost.

Installation of house regulators directly at separate gas supply buildings excludes costs for construction and operation of low-pressure street gas distribution pipelines and provides additional reduction of total costs for the construction and operation of settlement gas supply systems. An important advantage of single-stage gas supply systems with house regulators is also the possibility of stabilizing gas pressure in front of gas-using facilities. This allows to operate the gas equipment of buildings at gas pressures close to the nominal value, ensures the operation of gas appliances with the maximum efficiency and opens up significant reserves of gas conservation.

Long-term foreign experience in the operation of single-stage gas supply systems, as well as the results of their approbation in native practice, demonstrate the high efficiency of these gas distribution systems and prove the expediency of their wide application as an alternative to two-stage gas supply systems [3 ÷ 5].

The feasibility study for the construction of the system (length, diameter, capital investment, etc.) is determined by a number of factors, the main of which are the nature of the layout and construction of the gas supply village and hourly gas costs. As follows from [6], low-pressure networks are practically independent of the settlement size and the distance to the gas distribution station. At the process of designing medium and high-pressure networks, the right choice of power points is an important optimization tool. Therefore, one of the directions for improving technical and economic characteristics of gas distribution systems is the choice of a rational "input depth" of medium-pressure networks into the overall structure of the gas distribution system [1, 7÷9]. The connection of medium-pressure gas pipelines to low-pressure gas pipelines leads to an increase of the diameter of gas pipelines, thus requiring additional capital investment. On the other hand, investments in a low-pressure network are reduced [9]. The solution of the issue in favor of one of these options depends on a number of factors: the size of the gas supply settlement, distance from the gas networks of medium (high) pressures; possibility of using different types of gas burners (their combination), the nature of the layout of the settlement (the nature of the building), the density of the gas-supplying population, the load, etc. As an alternative way to increase the economic efficiency of gas supply systems it is possible to consider the usage of single-stage pressure reduction systems, for example, using medium-pressure gas pipelines. Researches show us, that gas supply systems of medium-pressure are about 20÷30% more economical than low-pressure systems [5, 7]. In the late 70s of the last century, there were works based on the experience of gasification of the US and French cities, which recommended to use medium and high-pressure gas pipelines for small gas consumers. Application of such schemes assumed the installation of a large number of house gas regulators for each consumer. As practice shows, the provision of the required gas pressure on the gas-using equipment is achieved in case when the reduction point is placed as close as possible to the consumer, as at the same time, gas pressure is maintained at the required level regardless of the gas flow rate change and the best conditions for gas combustion are provided. This circumstance increases the operational reliability and efficiency of gas-using devices for all consumers due to the equal gas supply. Such systems with reliable controllers of small capacity are economical and technically more completed [9, 10]. In case of an increase in the gas pressure and the installation of pressure regulators in consumers, which does not require energy costs, it is possible to reduce construction and operational costs by several times (the metal consumption of gas pipelines is reduced to 40%, which provides an adequate cost reduction in comparison with costs in a two-stage scheme gas supply).

In modern gas practice, the option of gas distribution systems, which provides for two-stage gas supply systems with linear reduction points and house gas pressure stabilizers, is becoming increasingly widespread. In this case, low-pressure gas networks are operated at an increased (up to 0.1 MPa) gas
pressure and then lowering it before gas-consuming devices to a nominal value (2000 Pa) with the help of house gas pressure stabilizers [11].

The specific length of gas distribution networks is largely determined by the structure of the built-up settlement area. For existing and planned cottage settlements in the countryside, the following development options are typical: quarterly – for large settlements, dead-end – with accommodation of houses along dead-end roads – for medium and small towns and tape (line) buildings, usually used in small townships [5].

In general, the length of medium-pressure gas pipelines is determined by the occupancy of flats, density of the population in the gas supply area, and the number of gasified buildings (population density).

Various devices and equipment are being used with the use of gaseous fuel for household needs (heating furnaces, gas hot-water chambers, water heaters, household gas stoves, etc.) [12, 13].

The thermal efficiency of domestic gas aggregates is estimated by the efficiency coefficient, which is the ratio of the effective heat output, perceived by the heat receiver to the spent heat output [9].

The maximum efficiency of gas using is ensured by the operation of the apparatus at the nominal operating mode, namely, with the nominal heat output $N_{nom}$, which accords to the nominal gas pressure before aggregate of $P_{nom}$. In real conditions, household gas appliances operate in modes other than the nominal, that is, with increased or reduced gas pressure before aggregate [5, 6].

In the pressure range $P_{min} \leq P \leq P_{max}$ gas-using installations ensure stable combustion of gas, the necessary fullness of its combustion with a high efficiency coefficient. Operation of gas-using installations in a mode other than the nominal reduces the thermal efficiency of gas use [6].

A typical graph of the operational parameters of gas-using installations as a function of the relative gas pressure (relative power output) is shown in Figure 1.

![Figure 1](image-url)

**Figure 1.** Dependence of the efficiency, the temperature of the combustion products and the coefficient of excess air after the gas-using apparatus from the relative gas pressure [14]
Subject and research methods

According to the state standard the experimental determination of the efficiency requires measuring the consumption and temperature range of water heating, as well as the gas consumption and the heat of its combustion too. Small changes in the efficiency of gas-using installations in the range of their operating modes of exploitation (several percent) make high demands to the accuracy of experimental research, to minimization of the errors in measuring and controlling, and the processing of experimental data.

This fact causes an increased labor intensity of experimental work, it requires using of high-precision measuring equipment, special methods of statistical processing of experimental materials. So, when we are carrying out certification tests of gas water-heating devices, as a rule the efficiency is determined only at the nominal operating mode, and it corresponds to maximal thermal efficiency.

To make the experimental research of the hot-water appliances the relative efficiency coefficient might be used. It is the ratio of the efficiency of the gas apparatus at the current and nominal operating conditions:

$$\eta_{rel} = \frac{\eta}{\eta_{nom}}. \quad (1)$$

Then, using equation

$$\eta = \frac{m \times c(t_2 - t_1)}{B \times Q_{net}}, \quad (2)$$

we can compute

$$\eta_{rel} = \frac{m \times c(t_2 - t_1)B_{nom} \times Q_{net}}{B \times Q_{net} \times m_{nom} \times c(t_2^{nom} - t_1^{nom})} = \frac{m(t_2 - t_1)B_{nom}}{B \times m_{nom}(t_2^{nom} - t_1^{nom})}, \quad (3)$$

where $m$ is consumption of heated water, kg·h$^{-1}$; $c$ is specific heat of water, kJ·(kg·K)$^{-1}$; $t_1$ is water temperature before the apparatus, °C; $t_2$ is water temperature after the apparatus, °C; $B$ is gas consumption, m$^3$·h$^{-1}$; $Q_{net}$ is net calorific value of the gas, MJ·m$^{-3}$.

If the consumption of the water is constant in the current and nominal modes of operation ($m = m_{nom}$), equation (3) takes the following form:

$$\eta_{rel} = \frac{B_{nom}}{B} \times \frac{t_2 - t_1}{t_2^{nom} - t_1^{nom}}. \quad (4)$$

According to the great number of theoretical and experimental researches the gas consumption of the gas-using apparatus $B$, m$^3$·h$^{-1}$, is related to the gas pressure $P$, Pa, by the following ratio [14]:

$$B = b \sqrt{P}, \quad (5)$$

where $b$ is conduction of the apparatus, m$^3$·(h·Pa$^{1/2}$)$^{-1}$.

Then we have (with (5) and (4)):

$$\eta_{rel} = \left(\frac{P_{nom}}{P}\right)^{1/2} \times \frac{t_2 - t_1}{t_2^{nom} - t_1^{nom}}. \quad (6)$$

where $P$, $P_{nom}$ are the current and nominal gas pressure before the gas apparatus, Pa.

As we can see from (6), the experimental determination of the relative efficiency coefficient requires the measuring of the gas pressure before the gas hot water apparatus and the temperature parameters of the heated water only.
The absolute value of the efficiency coefficient is determined by recalculation using equation (7):

\[ \eta = \eta_{rel} \times \eta_{nom} \]  

(7)

where \( \eta_{nom} \) is maximum efficiency of the device, corresponding to the nominal mode of its exploitation. The values of \( \eta_{rel} \), obtained from the results of certification tests, are given in the passport data of gas water heaters.

Determination of the efficiency of gas hot water chambers and water heaters was carried out on an experimental installation.

Tests of gas apparatus were carried out at the following values of the initial water temperature:
- gas water heating chamber \( t_1 = 40 \, ^\circ{C} \);
- gas instantaneous water heater \( t_1 = 18 \, ^\circ{C} \).

The final water temperature at the output from the apparatus at the nominal operating mode \( (P_{nom} = 200 \, \text{dPa}) \) was ensured with the following limits:
- gas water heating chamber \( t_2^{nom} = 60 \, ^\circ{C} \);
- gas instantaneous water heater \( t_2^{nom} = 58 \, ^\circ{C} \).

In order to justify the choice of a rational option of gas distribution systems there were carried out relevant technical and economic studies. As an objective function of the problem, specific annual costs (per building) were used for the gas supply system for the complex: gas networks the consumer. In the general case, the initial functionals of the problem under study have the following form (formulas 8÷10):

- option 1 (two-stage scheme with linear reduction points):

\[ \Delta C_1 = C_{gs}^{mp} (q, S, n) + C_{gr} (V, n) + C_{gs}^{lp} (q, S, V, \Delta P) + \Delta T \{\eta_{ga} [P_g (\Delta P)], V_{\Sigma y} \} \]  

(8)

- option 2 (single-stage system with individual reduction points):

\[ \Delta C_2 = C_{gs}^{mp} (q, S) + C_{gr} (V) + C_{gs}^{lp} (q, S, V, \Delta P) \]  

(9)

- option 3 (two-stage scheme with linear reduction points and house gas pressure stabilizers):

\[ \Delta C_3 = C_{gs}^{mp} (q, S, n) + C_{gr} (V, n) + C_{gs}^{lp} (q, S, V, \Delta P) + C_{st} \]  

(10)

where \( C_{gs}^{mp}, C_{gs}^{lp} \) are the costs in the medium and low pressure networks, including intra-yard and home gas pipelines, RUB·(year·sq)\(^{-1}\); \( C_{gr} \) is gas regulating installations expenses, RUB·(year·sq)\(^{-1}\); \( C_{st} \) is house gas stabilizers expenses, RUB·(year·sq)\(^{-1}\); \( \Delta T \) is annual cost of an additional consumable gas, RUB·(year·sq)\(^{-1}\); \( q \) is a population density, person/ha; \( S \) is average occupancy of apartments, person/sq.; \( n \) is the optimal number of apartments (houses) connected to one reduction point, sq; \( V \) is hour maximum gas consumption per apartment, \( m^3/(p \cdot sq) \), is taken according to [9], depending on the nature of the gas-using equipment and its operating modes; \( V_{\Sigma y} \) is annual gas consumption per apartment, \( m^3/(year \cdot sq) \); \( \Delta P \) is optimum design pressure drop in gas pipelines, Pa; \( \eta_{ga} \) is an efficiency of gas-using units, \% (taken according to [9], depending on the pressure of the gas used, Pa).

Results

The results of experimental studies are shown in Table 1, using the AOGV-10 chamber with several operating modes as the example.
Table 1. Results of experimental studies of the AOGV-10 chamber

1) Nominal test mode: $P_{\text{nom,av}} = 200.3$ daPa; $t_{2,\text{av}}^{\text{nom}} = 60.0$ °C; $t_{1,\text{av}}^{\text{nom}} = 40.02$ °C

| Number of experiments | $P_{\text{nom}}$ (daPa) | $P_{\text{nom,av}}$ (daPa) | $t_2^{\text{nom}}$ (°C) | $t_{2,\text{av}}^{\text{nom}}$ (°C) | $t_1^{\text{nom}}$ (°C) | $t_{1,\text{av}}^{\text{nom}}$ (°C) | $\eta_{\text{rel}}$ |
|-----------------------|--------------------------|----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|-----------------|
| 1                     | 201                      |                            | 60.0                     |                           | 39.9                     |                          |                 |
| 2                     | 201                      |                            | 60.1                     |                           | 40.1                     |                          |                 |
| 3                     | 202                      | 200.3                     | 59.9                     | 60.0                     | 40.2                     | 40.02                    | 1               |
| 4                     | 199                      |                            | 59.8                     |                           | 39.9                     |                          |                 |
| 5                     | 199                      |                            | 60.1                     |                           | 40.1                     |                          |                 |
| 6                     | 200                      |                            | 60.1                     |                           | 39.9                     |                          |                 |

2) Test mode: $P_{\text{av}} = 75.5$ daPa; $t_{2,\text{av}} = 51.5$ °C; $t_{1,\text{av}} = 39.9$ °C

| Number of experiments | $P_{\text{av}}$ (daPa) | $P_{\text{av,av}}$ (daPa) | $t_2$ (°C) | $t_{2,\text{av}}$ (°C) | $t_1$ (°C) | $t_{1,\text{av}}$ (°C) | $\eta_{\text{rel}}$ |
|-----------------------|--------------------------|---------------------------|------------|--------------------------|------------|--------------------------|-----------------|
| 1                     | 74                       |                           | 51.4       |                           | 40.0       |                          |                 |
| 2                     | 76                       |                           | 51.7       |                           | 40.1       |                          |                 |
| 3                     | 77                       | 75.5                      | 51.4       | 51.5                     | 39.9       |                          | 0.947           |
| 4                     | 75                       |                            | 51.4       |                           | 40.1       |                          |                 |
| 5                     | 77                       |                            | 51.5       |                           | 39.9       |                          |                 |
| 6                     | 74                       |                            | 51.6       |                           | 39.8       |                          |                 |

3) Test mode: $P_{\text{av}} = 100.3$ daPa; $t_{2,\text{av}} = 53.15$ °C; $t_{1,\text{av}} = 40.03$ °C

| Number of experiments | $P_{\text{av}}$ (daPa) | $P_{\text{av,av}}$ (daPa) | $t_2$ (°C) | $t_{2,\text{av}}$ (°C) | $t_1$ (°C) | $t_{1,\text{av}}$ (°C) | $\eta_{\text{rel}}$ |
|-----------------------|--------------------------|---------------------------|------------|--------------------------|------------|--------------------------|-----------------|
| 1                     | 100                      |                           | 53.2       |                           | 40.0       |                          |                 |
| 2                     | 102                      |                           | 52.9       |                           | 40.2       |                          |                 |
| 3                     | 99                       | 100.3                     | 53.2       | 53.15                    | 39.9       |                          | 0.96            |
| 4                     | 99                       |                            | 53.3       |                           | 39.9       |                          |                 |
| 5                     | 101                      |                            | 53.2       |                           | 39.9       |                          |                 |
| 6                     | 101                      |                            | 53.1       |                           | 40.1       |                          |                 |

4) Test mode: $P_{\text{av}} = 150.6$ daPa; $t_{2,\text{av}} = 57.0$ °C; $t_{1,\text{av}} = 40.01$ °C

| Number of experiments | $P_{\text{av}}$ (daPa) | $P_{\text{av,av}}$ (daPa) | $t_2$ (°C) | $t_{2,\text{av}}$ (°C) | $t_1$ (°C) | $t_{1,\text{av}}$ (°C) | $\eta_{\text{rel}}$ |
|-----------------------|--------------------------|---------------------------|------------|--------------------------|------------|--------------------------|-----------------|
| 1                     | 151                      |                           | 57.2       |                           | 39.8       |                          |                 |
| 2                     | 152                      |                           | 57.0       |                           | 39.9       |                          |                 |
| 3                     | 151                      |                           | 56.9       |                           | 40.1       |                          |                 |
| 4                     | 149                      | 150.6                     | 57.2       | 57.0                     | 40.2       |                          | 0.99            |
| 5                     | 152                      |                            | 57.1       |                           | 40.1       |                          |                 |
| 6                     | 149                      |                            | 57.0       |                           | 40.0       |                          |                 |
5) Test mode: $P_{av} = 175.5 \text{ daPa}; \quad t_{2,av} = 58.5 ^\circ \text{C}; \quad t_{1,av} = 40.05 ^\circ \text{C}$

| Number of experiments | $P_\text{av}$ (daPa) | $P_{av}$ (daPa) | $t_2$ (°C) | $t_{2,av}$ (°C) | $t_1$ (°C) | $t_{1,av}$ (°C) | $\eta_{rel}$ |
|-----------------------|-----------------------|-----------------|-----------|-----------------|-----------|----------------|--------------|
| 1                     | 176                   | 176             | 58.6      | 58.5            | 39.9      | 40.05          | 0.996        |
| 2                     | 177                   | 175.5           | 58.5      | 58.5            | 39.9      | 40.1           |              |
| 3                     | 174                   | 58.4            | 40.1      |                 |           |                |              |
| 4                     | 176                   | 58.5            | 40.1      |                 |           |                |              |
| 5                     | 174                   | 58.7            | 40.2      |                 |           |                |              |
| 6                     | 176                   | 58.7            | 40.1      |                 |           |                |              |

6) Test mode: $P_{av} = 250.3 \text{ daPa}; \quad t_{2,av} = 61.0 ^\circ \text{C}; \quad t_{1,av} = 41.1 ^\circ \text{C}$

| Number of experiments | $P_\text{av}$ (daPa) | $P_{av}$ (daPa) | $t_2$ (°C) | $t_{2,av}$ (°C) | $t_1$ (°C) | $t_{1,av}$ (°C) | $\eta_{rel}$ |
|-----------------------|-----------------------|-----------------|-----------|-----------------|-----------|----------------|--------------|
| 1                     | 251                   | 251             | 60.9      | 61.0            | 41.2      | 41.1           | 0.993        |
| 2                     | 249                   | 250.3           | 61.0      | 61.0            | 41.2      | 41.1           |              |
| 3                     | 251                   | 61.2            | 40.9      |                 |           |                |              |
| 4                     | 252                   | 61.2            | 41.0      |                 |           |                |              |
| 5                     | 250                   | 61.1            | 41.1      |                 |           |                |              |
| 6                     | 249                   | 61.0            | 41.0      |                 |           |                |              |

As we can see from Table 1, the test modes of the chamber have a significant effect on the efficiency of gas fuel using.

If the chamber is operated at nominal mode with a pressure 200 daPa, the relative efficiency is equal to one, then when the pressure decreases to 75 daPa, (the thermal power is reduced to 2/3 of the nominal one), the relative efficiency is reduced to 0.947, i.e., more than 5%. The similar situation is observed with an increased gas pressure.

The resulting error in the experimental values of the relative efficiency of the chamber is in the range 1.4–2.1 with a confidence probability of 0.95, and it corresponds to the state standard requirement for the accuracy of experimental researches.

Similar results were obtained for other types of gas water-heating apparatus.

The processing of the experimental array of experimental data by the methods of correlation analysis revealed a close connection between the investigated function $\eta_{rel} = \frac{\eta}{\eta_{nom}}$ and the control parameter $P_{rel} = \frac{P}{P_{nom}}$.

The results of the experimental studies are approximated by the following dependence with a correlation coefficient of 0.88877:

$$\eta_{rel} = -0.5136 P_{rel}^6 + 2.3548 P_{rel}^5 - 3.0664 P_{rel}^4 - 0.7648 P_{rel}^3 + 4.4265 P_{rel}^2 - 2.9919 P_{rel} + 1.553.$$  \hspace{1cm} (11)

The presence of this connection provides the necessary prerequisites for optimizing the hydraulic operating modes of distribution systems of gas supply, taking into account the efficiency of using gas fuel by consumers.
For the purpose of numerical realization of the target functions, the corresponding calculations were made. The object of gas supply was a settlement with a manor building, located in a moderately cold climatic zone. Gas equipment for flats was used for gas stoves and gas heating stoves. Calculation results are presented in Table 2.

**Table 2. Comparative economic efficiency of options of gas distribution systems**

| Gas supply system option | Two-stage with gas storage units (option 1) | Single-stage with house gas pressure regulators (option 2) | Two-stage house gas pressure stabilizers (option 3) |
|--------------------------|---------------------------------------------|----------------------------------------------------------|-----------------------------------------------|
| Annual discounted costs, C, [RUB·(year·sq⁻¹)] | 3136                                        | 3628                                                      | 2421                                          |

As can be seen from Table 2, the most economical option is a two-stage gas supply system with house gas pressure stabilizers (option 3). Application of this option provides reduction in the annual discounted costs for the construction and operation of the village gas supply system:

- compared with option 2: \( \Delta Z = 33.3\% \);
- compared with option 1: \( \Delta Z = 23.8\% \).

It is worth noting that option «2» and «3» of the gas distribution system determine the operation of gas-using units at gas pressure close to the nominal (due to the constant pressure at the output of the house regulator or apartment gas pressure stabilizer). At the same time, option «1» determines the operation of gas-using units under reduced gas pressure (due to pressure losses in distribution gas pipelines). As a consequence, the efficiency of gas-using plants is reduced by 2 ÷ 3% and gas consumption is adequately increased.

As follows from the analysis, the specific costs for gas supply systems are determined by the nature of the built-up area, the density of the population in the gas supply territory, and technical characteristics of the gas supply buildings.

Research results provide necessary methodological prerequisites for the solution of the actual scientific and technical problem - substantiation for the rational application of one and two-stage gas supply systems using gas storage units.

As target functions of this technical and economic task, we will take specific reduced costs for alternative gas supply systems: two-stage with gas storage units \( C_{gs}^{ts}(q,n_{opt}) \) and single-stage with house gas pressure regulators \( C_{gs}^{ss}(q) \). The problem is solved by the method of critical points. Equating the costs for the compared options, we determine the critical value of the control parameter - critical population density \( q_{cr} \), in which alternative gas supply systems are economically equivalent. Then, analyzing the costs in the region \( q < q_{cr} \), we take the option with less expenses for each of the regions.

Calculations results are illustrated by the plots in Figures 2, 3, 4.

As can be seen from the graphs, single-stage gas supply systems are economically feasible in settlements with single-row construction with population density \( q \leq 65\text{-}75 \) person/ha (area of infield area \( \geq 0.04\text{-}0.05 \) ha).

For settlements with two-row building, the area of rational use of single-stage gas supply systems is limited by the condition \( q \leq 35\text{-}40 \) person/ha (the area of the infield area is \( \geq 0.07\text{-}0.08 \) ha).

For multi-row settlements, single-stage gas supply systems are economically justified at population density of \( q \leq 10\text{-}20 \) person/ha (the area of the infield is \( \geq 0.15\text{-}0.30 \) ha).

Taking into account error in calculating the costs in the amount of 3\text{-}5% for use in project practice, the following generalized recommendations are proposed:
single-stage gas supply systems are expedient for use in settlements with tape (one and two-row) buildings with the area of personal plots of 0.04-0.06 and more hectares. In all other cases it is advisable to use two-stage gas supply systems in conditions of their optimal centralization.

Figure 2. Determination of the expedient use of single and two-stage gas distribution systems (single-row construction): 1 – single-stage gas supply systems; 2 – two-stage gas supply systems

Figure 3. Determination of the expedient use of single and two-stage gas distribution systems (two-row construction): 1 – single-stage gas supply systems; 2 – two-stage gas supply systems
Figure 4. Determination of the expedient use of single and two-stage gas distribution systems (multi-row construction): 1 – single-stage gas supply systems; 2 – two-stage gas supply systems

Summary
1. A retrospective development analysis of distribution systems for gas supply to settlements reveals a tendency to reduce degree of their centralization through the wide introduction of gas storage units and single-stage gas supply systems equipped with house pressure regulators.
2. A great number of scientific publications are devoted to the issue of the optimal settlement gas supply systems functioning, however, the solutions received by the authors and the recommendations developed on their basis are fragmentary, often contradictory, since they do not take into account the fullness and variety of interaction of system-forming factors. They are developed, generally, on the basis of gas equipment of the 1960s and 1970s, and therefore cannot be fully claimed in modern gas practice.
3. Due to results of technical and economic calculations, it was established that in the case of gas supply to consumers using a two-stage gas supply system with house gas pressure stabilizers, annual discounted costs for the construction and operation of the gas supply system are reduced:
   - compared with option 2: $\Delta Z = 33.3\%$;
   - compared with option 1: $\Delta Z = 23.8\%$.
4. One-stage gas supply systems should be used primarily in towns with tape (single and double-row) buildings with the area of household plots of 0.04÷0.06 and more hectares, as well as in settlements with multi-row building with the area of personal plots of 0.15÷0.30 and more hectares. In other cases, it is advisable to use two-stage gas supply systems in conditions of their optimal centralization.
5. These values correlate with the results of other researchers and, at the same time, more adequately reflect the specific features of the functioning of settlement gas supply systems, taking into account the variety of system-forming links and factors.

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