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COMPARATIVE EVALUATION OF THE ENERGY AND ECONOMIC EFFICIENCY THE GAS SUPPLY SYSTEMS OF SMALL TOWNS

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Statement of the problem. 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.

Results. 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, i. e. at maximum efficiency.

Conclusions. 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. Installation of household stabilizers gas pressure also provides fuel savings. In the presence of stabilizers gas-installations can operate at a pressure of the gas is close to par, i. e. with maximum efficiency. The research results lead to the conclusion about the effectiveness of the use gas network of medium pressure, followed by pressure reduction up to the required values of household pressure regulators or regulators-stabilizers.

Keywords: gas distribution network, gas pressure regulator, gas pressure stabilizer, annual adjusted cost, pressure rating, energy efficiency.

Introduction. Presently one of the most important tasks for providing fuel resources is to develop and employ the latest technologies of energy supply that cannot be evaluated only based on optimization of the parameters to make them as much cost- and material-efficient as possible. Therefore the development of a set of energy supply measures choosing organizational and technical solutions to provide a necessary mode of distribution and consumption of gas fuel is an urgent scientific issue.

In modern gas practices for gas supply of residential areas a two-step gas supply systems based on a gas reduction station that looks like a cabinet that are installed for a group of users. The above systems include gas distribution networks of high (from 0.3 to 0.6 MPa (Category II) and from 0.6 to 1.2 MPa (category I)) or medium (from 0.1 to 0.3 MPa) pressure as well as gas distribution of low pressure (including 0.1 MPa to the pressure controller).

Distribution networks of low pressure are commonly designed to let in gas volumes at a specified pressure loss that complies with the requirements for stable performance of gas-operating setups.

According to recommendations [11], a calculation period of a pressure gradient in a gas reduction station in the conditions of a maximum hourly gas consumption is

— for tools with a nominal pressure $P_{ном}^{приб}$ = 2000 Pa: ΔP_p = 150 Pa;

— for tools with a nominal pressure $P_{ном}^{приб}$ = 1300 Pa: ΔP_p = 596 Pa.

There is a practice of operating distribution pipelines of low pressure that causes a low calculation pressure gradient and thus a high material cost of gas networks. One of ways to reduce material costs of gas networks is known to be an increase in the operational pressure in gas distribution systems. Note, however, that an increase in the operational pressure in gas networks has a negative impact on the operation of gas-operating setups. There is a danger of a breakaway and extinction of a flame, which might give rise to an emergency.

An important reserve for increasing economic efficiency of gas distribution networks is the use of one-step gas supply systems. In this case gas is supplied along gas pipelines of high (medium) pressure. A reduction in the gas pressure prior to its supply is in the gas reduction station that are fitted with household pressure controllers. These systems with reliable controllers with a low productivity are viable economically and technically, i.e. there is constant gas pressure in the tools and gas is burnt in the best conditions. According to the research, gas supply systems of medium pressure are about 20…30 % more cost-efficient than low-pressure systems [1, 4, 10, 12, 22].

In different countries gas pressures in gas supply systems vary considerably (Fig. 1) [13, 15—21].

In European countries apart from controllers on external gas networks, there are individual redactors that are installed immediately in front of gas-operating equipment. This provides optimal operation of setups with a maximum efficiency and minimizes the content of hazardous substances in combustion products.

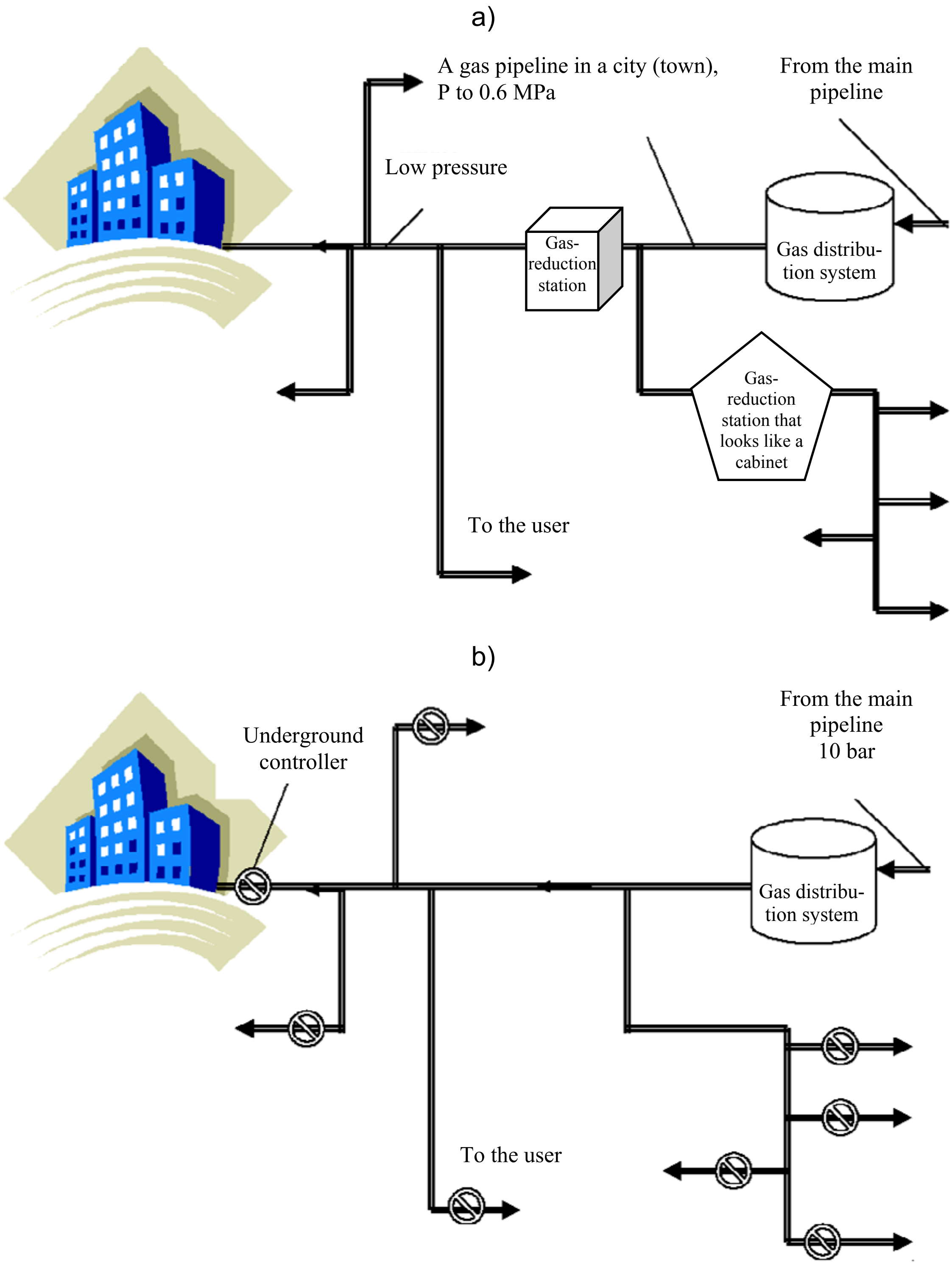

Fig. 1. Typical schemes of gas distribution systems:

a) gas distribution systems of a Russian residential area: pressure at the time of nominal consumption — 130 millibar, in the remaining time — 170…180 millibar, pressure at the output from a gas-regulating station — 180 millibar; b) gas distribution systems in European residential areas: pressure is constant and complies with a nominal gas pressure of gas tools

In addition, in order to improve safety there are “gas-stop” shutoff valves. The valve mechanism detects an increase in the gas consumption caused by damage of the input gas pipeline. While inside a pipeline, the valve does not restrain a gas flow and for standard oscillations in consumption it remains open, but once consumption of gas exceeds a preliminarily specified value, the valve self-activates and shuts to prevent a gas leak and thus inflammation and explosion. In this country there has been some positive experience in using these valves in distribution gas supply systems.

A necessary gas pressure in gas-operating equipment is provided when a gas operating station is located as close to the user as possible with

— the pressure stability that is retained in specified ranges regardless of oscillations of gas pressure, which improves the reliability of the operation and efficiency of tools for all users due to even distribution of gas supply;

— removing the impacts caused by the relief of an area.

As a gas pressure increases, which requires no energy, and installation of pressure controllers might reduce construction and operation costs by several times (a specific quantity of metal for gas pipelines is reduced by 40 %, which provides a sufficient decrease in integral costs compared to those for a two-step gas supply schemes).

Relatively small volumes of gas consumption in rural areas including small towns and villages for a low density of residential areas provide good conditions for using a one-step systems of gas supply of medium pressure [9]. Note that, however, the recommendations in [9] are not sufficiently justified. A reduction in a specific quantity of metal of gas networks is an important but not the only factor that determines economic efficiency of gas supply systems. Replacement of gas pipelines of low pressure for those of medium pressure not only reduces a specific quantity of metal in gas networks but it also increases its operational costs. 1 pm of a medium-pressure gas pipeline is 2.5 times higher than that of 1 pm of a low-pressure gas pipeline.

Installing gas reduction stations next to each gas supplied building causes a sharp increase in capital costs of gas-regulating setups and their operation. Considering the above, the sue of one-step gas supply systems requires a more in-depth technical and economic analysis [5].

The choice of an optimal and most reliable variant is considerably influenced by a characteristics of a gas supply object, i.e. planning of a residential area, density and construction heights, gas consumption, gas consumption setups, cost of pipes, equipment, etc.

For optimal gas supply options the following most common structural schemes of a distribution systems of residential areas consisting of houses with different service levels (a different level of gas consumption).

Presently in this country for gas supply of rural residential areas and cottage towns two main schemes of gas distribution systems are common [5, 7, 14]:

— a two-step scheme with linear reduction stations that look like a cabinet (variant a): includes distribution networks of high (medium) pressure, distribution gas networks of low pressure as well as linear reduction stations that provide a reduction in the gas pressure from a high to a low one;

— a one-step scheme with individual reduction stations that look like a cabinet (variant b): all gas distribution networks are operated on a high (medium) pressure followed by a reduction in the gas pressure using individual household controllers of gas pressure.

In modern gas practice the third variant of gas distribution systems (variant c) is becoming increasingly common which involves a two-step variant of a gas supply system with a linear reduction stations and household regulators of gas pressure. In this variant low-pressure gas networks are used at an exceedingly high (up to 0.1 MPa) gas pressure followed by its reduction before gas-operating tools up to a nominal value (2000 Pa) using household gas pressure stabilizers.

The described calculation schemes of gas distribution systems are given in Fig. 2.

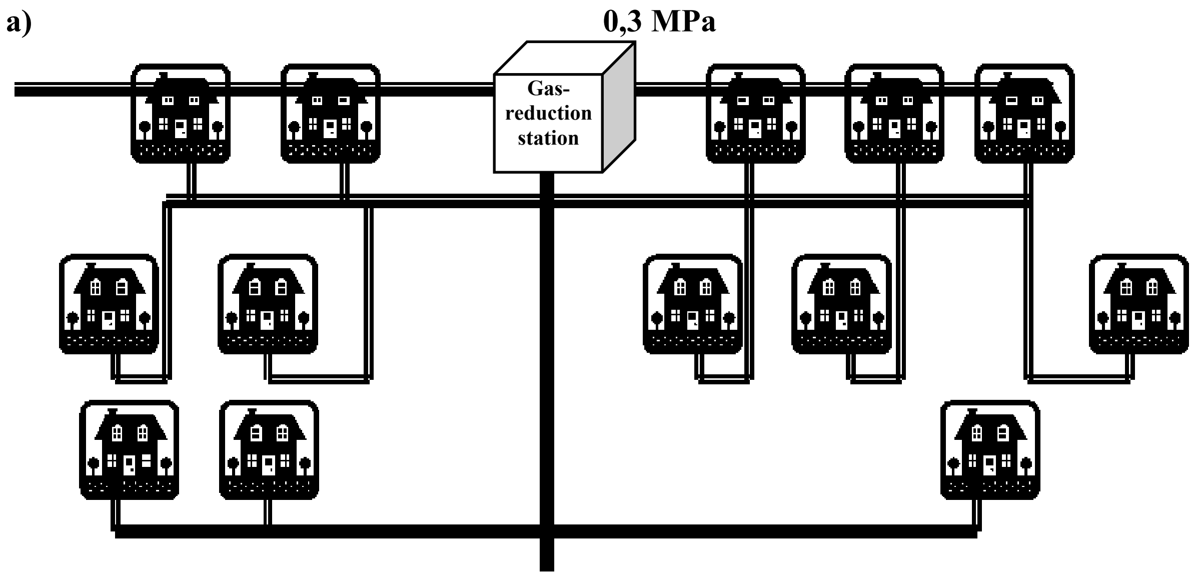

Fig. 2. Modern schemes of gas distribution systems:
a) a two-step scheme with linear reduction stations

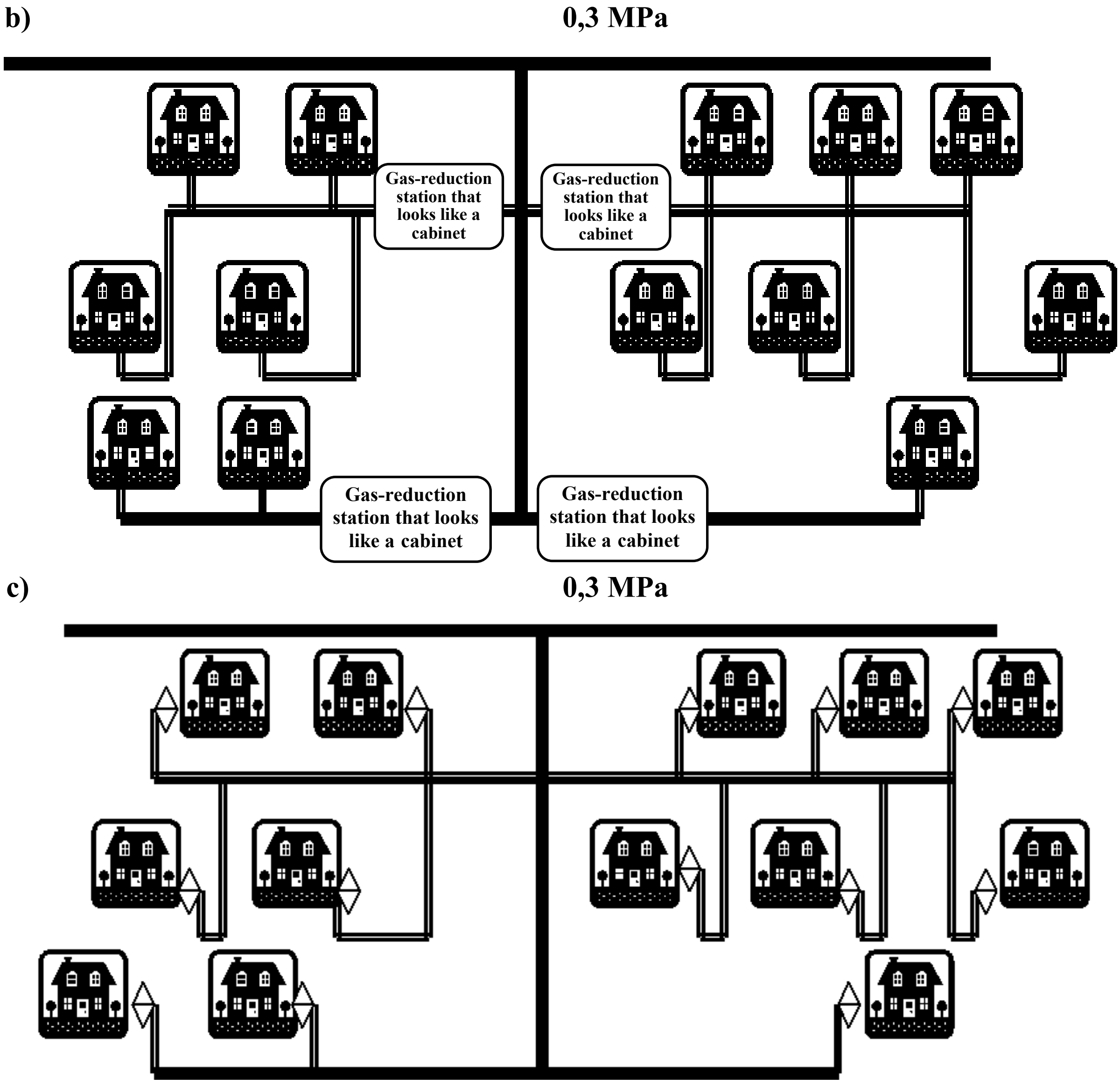

Fig. 2 (end). Modern schemes of gas distribution systems:

◊ is a household gas controller

b) a one-step system with individual reduction stations that look like cabinets;

c) a two-step scheme with linear reduction stations and household gas pressure stabilizers

1. Justification of a calculation pressure gradient of a gas distribution system. One of the most important grounds for calculating gas distribution systems of towns are calculation pressure gradients in distribution gas pipelines for household gas pressure stabilizers.

It is known that optimal operation of gas tools is provided at a gas pressure that is close to a nominal value. Gas tools that are used in households such as gas stoves, water heaters, furnaces, etc. are manufactured by the country's enterprises for two nominal gas pressures

$P_{ном}^{приб}$ = 1300 and 2000 Pa. The operating gas pressure before a tool is largely different from a nominal value. If a gas tool is joined to a route of a distribution pipeline at the start, the tool operates at an exceeded gas pressure. Tools that are joined to the end of the route of a gas distribution pipeline operate at a low gas pressure respectively.

A maximum acceptable range of changes in the pressure in the gas supply system is

$$\Delta P_{\max} = \Delta P_{\max}^{приб} - \Delta P_{\min}^{приб}, \quad (1)$$

where $\Delta P_{\max}^{приб}$ is a maximum acceptable gas pressure; $\Delta P_{\min}^{приб}$ is a minimum acceptable gas pressure. We assume that [7]:

— for tools with an exceedingly high nominal pressure $\Delta P_{ном}^{приб}$ = 2000 Pa, $\Delta P_{\max}^{приб}$ = 2500 Pa, $\Delta P_{\min}^{приб}$ = 1700 Pa;

— for tools with an exceedingly low pressure $\Delta P_{ном}^{приб}$ = 1300 Pa, $\Delta P_{\max}^{приб}$ = 1764 Pa, $\Delta P_{\min}^{приб}$ = 650 Pa.

Therefore a maximum acceptable pressure gradient

— at a nominal pressure 2000 Pa: $\Delta P_{\max}^{приб}$ = 800 Pa;

— at a nominal pressure 1300 Pa: $\Delta P_{\max}^{приб}$ = 1114 Pa.

The fact that in the second case a range of a possible pressure gradient goes up is due to the fact that tools with an exceedingly low nominal gas pressure are more stable against backflashes and isolation of flame. This indicates that the use of tools with a nominal gas pressure of 1300 Pa is most preferable.

Presently reduction stations that look like cabinets include a complex of technological equipment that provides control of gas pressure and safe operating modes of gas supply systems as well as gas pressure controllers and safety shut-off valves and safety discharge valves.

According to the safety requirements, the upper range of the operation of safety shut-off valves $P_{кпз}^{верх}$ comply with the condition:

$$\Delta P_{\max}^{рег} \langle P_{пск} \langle P_{кпз}^{верх}. \quad (2)$$

As a rule, a safety shut-off valve is adjusted to the pressure of operation that exceeds a controlled gas pressure by 25 %, a safety discharge valve is adjusted to the pressure that exceeds a controlled pressure by 15 % [20]:

$$P_{\max}^{рег} = \Delta P_{\max}^{приб}, \quad (3)$$

where $P_{\max}^{рег}$ is a maximum pressure at the output of the pressure controller.

A gas reduction station that looks like a cabinet is equipped with direct gas pressure controllers. These controllers do not provide consistently stable output pressure. At a maximum input gas pressure and its consumption that is close to zero, the output pressure reaches a maximum value $P_{\max}^{рег}$. At a minimum input gas pressure and its maximum consumption the input pressure reaches its minimum value $P_{\min}^{рег}$. A degree of uneven distribution for this type of gas pressure controller is ±10 % of the input pressure in the entire range of changes in the gas consumption at the oscillations of the input pressure ±25 % of its average value.

Hence

$$\frac{P_{\max}^{рег} - P_{ср}^{рег}}{P_{ср}^{рег}} = \frac{P_{ср}^{рег} - P_{\min}^{рег}}{P_{ср}^{рег}} = 0.1; \tag{4}$$

$$P_{\min}^{рег} = 0.82 P_{\max}^{приб}.$$

A lower limit of the operation of safety shut-off valves meets the condition:

$$P_{кпз}^{нижс} \le P_{\min}^{рег} - 500 \text{ Pa}.$$

The valve switches on during an emergency in a gas supply system (tearing or leaking of a gas pipeline).

A minimum suggested pressure gradient in a gas network at a minimum value of the controlled pressure is

$$\Delta P_{\min}^{p} = P_{\min}^{рег} - \Delta P_{сч} - P_{\min}^{приб} = 0.82 P_{\max}^{приб} - \Delta P_{сч} - P_{\min}^{приб}, \tag{5}$$

where $\Delta P_{сч}$ are pressure losses in the tools considering the gas consumption (meters), Pa.

$$\Delta P_{\max}^{p} = P_{\max}^{рег} - \Delta P_{сч} - P_{\min}^{приб} = P_{\max}^{приб} - \Delta P_{сч} - P_{\min}^{приб}. \tag{6}$$

A minimum gas pressure at the output of a gas reduction station that looks like a cabinet is given by the formula [1] and is as follows

$$P_{\min}^{рег} = 0.82 P_{\max}^{рег} = 4200 \text{ Pa}, \tag{7}$$

where $P_{\max}^{рег}$ is a maximum gas pressure at the output of the gas reduction station that looks like a cabinet, Pa.

2. Distribution gas supply systems with household gas pressure stabilizers. The main measures for safe gasification of buildings are listed in the latest edition of Health and Safety Regulations 62.13330.2011* “Gas Distribution Systems” (section 7 and Appendix D) and according to them, controllers and stabilizers (according to the GOST 54086-2010 “Pressure Controllers and Protective Tools Joining them for Gas Tools” and GOST P 54824-2011 and

“Pressure Stabilizers. General Technical Conditions”) are to be installed at a gas pressure in internal gas pipelines of over 0.0025 MPa. Due to construction features, controllers and stabilizers are not only stabilizers of gas pressure but also those of gas consumption and provide an optimal mode of gas combustion. If the requirements of Health and Safety Regulations 62.13330.2011* are complied with when it comes to the use of gas pressure stabilizers, a peak increase in the gas pressure in internal pipelines over 0.1 MPa before gas-operating equipment will be smoother and the gas consumption will drop to the set value.

A common use of two-step gas supply systems with household gas pressure stabilizers requires more scientifically viable methods, calculations and design.

In accordance with the technical requirements to gas pressure stabilizers, the latter provide a maximum uneven distribution of output pressure control of ±10 %.

Assuming that

$$\frac{P_{\max}^{cm} - P_{cp}^{cm}}{P_{cp}^{cm}} = \frac{P_{cp}^{cm} - P_{\min}^{cm}}{P_{cp}^{cm}} = 0.25, \quad (8)$$

we get $P_{\min}^{cm} = 0.6 P_{\max}^{cm} = 3000$ Pa where $P_{\min}^{cm}$, $P_{\max}^{cm}$, P_{cp}^{cm} is a maximum, minimum and average gas pressure at the input of the stabilizer, Pa.

A calculation pressure gradient from a gas reduction station that looks like a cabinet to a stabilizer considering the loss of pressure in the user’s gas meter $\Delta P_{сч}$ [8] is

$$\Delta P^{p} = P_{\min}^{рег} - P_{\min}^{cm} - \Delta P_{сч} = 1000 \text{ Pa}. \quad (9)$$

Therefore the use of two-step gas supply systems with household gas pressure stabilizers increases a calculation pressure gradient in gas distribution networks from 150 (596) to 1000 Pa, i.e. by 1.68—6.66 times.

As the diameter of distribution gas pipelines of low pressure is proportionate to a calculation pressure gradient in the degree of 0.21 [3], the specified increase in the calculation gradient reduces the diameters of gas distribution systems by 12…49 % during a sufficient decrease in the material costs of gas supply systems.

3. Technical and economic justification of designing solutions. An exceedingly high gas pressure considerably increases the release capacity of low-pressure gas pipelines. This circumstance leads to a decrease in the diameters of distribution networks and opens up significant resources for reducing material and capital costs of gas supply systems.

Stabilization of gas pressure before a gas-opertaing setups allows one to operate the latter under a constant input pressure that corresponds with a nominal value. This improves the performance of the tools at a maximum efficiency and also opens up extra gas-saving reserves.

In order to account for the choice of a viable variant of gas distribution systems of rural residential areas with farming construction, the corresponding technical and economic studies have been conducted. As an objective function, specific (for one building) annual discounted costs of a gas supply system in the complex “gas supply networks of high/medium pressure — user” were employed.

Generally the initial functionals of the investigated task are as follows:

— variant a:

$$\Delta З_А = З_{ГС}^{СД}(q,s,n) + З_{пргш}(V,n) + З_{ГС}^{НД}(q,s,V,\Delta P) + \Delta T\left\{\eta_г\left[P_г(\Delta P)\right], V_{год}\right\}; \quad (10)$$

— variant b:

$$\Delta З_Б = З_{ГС}^{СД}(q,s) + З_{пргш}(V,n) + З_{ГС}^{НД}(q,s,V,\Delta P); \quad (11)$$

— variant c:

$$\Delta З_В = З_{ГС}^{СД}(q,s,n) + З_{пргш}(V,n) + З_{ГС}^{НД}(q,s,V,\Delta P) + З_{сд}, \quad (12)$$

where $З_{ГС}^{СД}, З_{ГС}^{НД}$ are the costs in a network of high/medium pressure, costs in a network of low pressure including gas pipelines inside a yard and a house, roubles/(year·sq); $З_{пргш}$ are the costs of gas controlling setups, roubles/(year·sq); $З_{сд}$ are the costs of household stabilizers of the gas pressure, roubles/(year·sq.); ΔT is the annual cost of extra gas duw to the operation of gas-operating setups at a gas pressure that is different from a nominal value, roubles/(year·sq.); q is the population density in a town where gas is supplied, person/m^2; s is the average population level of apartments, person/sq.; n is an optimal number of apartments (houses) that are joined to the same reduction station, sq. (as specified in the recommendations [11]); V is a maximum hourly gas consumption in one apartment, m^3/(h·sq.) (as specified in the recommendations [11] depending on the character of gas-operating equipment and its operation modes); $V_{год}$ is annual gas consumption by one apartment, m^3/(year·sq.) [11]; ΔP is a calculation pressure gradient in distribution gas pipelines of low pressure, Pa (as specified in the recommendations [4, 6, 11]); $\eta_г$ is the efficiency of gas-operating setups, % (as specified in the recommendations [11] depending on the pressure of the used gas $P_г$).

As a result of the study, theoretical dependencies that reveal a certain content of the components of objective functions were developed (10…12).

For a numerical implementation of the objective functions, the corresponding calculations were performed. A gas supply object was a rural residential area with farming construction located in a moderately cold climate zone. The gas equipment of the apartments was gas stoves and furnaces operated in the recurrent heating mode.

The results of the calculations are presented in Table.

Table

Comparative economic efficiency of the variants of gas distribution systems

Gas supply variant	Two-step system with reduction stations that look like cabinets (variant a)	One-step system with household controllers of gas pressure (variant b)	Two-step system with household stabilizers of gas pressure (variant c)
Annual discounted costs *З*, roubles/(year ·sq.)	3136	3628	2421

As seen from Table, the most cost efficient is the variant of a two-step system of gas supply with household gas pressure stabilizers (variant c). The use of the above variant provides a reduction in the annual discounted costs for design and operation of a gas supply system of a town:

— compared to the variant b: $\Delta З = 33.3$ %;

— compared to the variant a: $\Delta З = 23.8$ %.

Also note that the variants b and c of a gas distribution system are essential to the operation of gas-operating setups at a gas pressure similar to a nominal one (due to the constance of the output pressure of a household controller or a gas pressure stabilizer in an apartment). At the same time the variant a is essential to the operation of gas-operating setups at an exceedingly low gas pressure (due to losses in distribution gas pipelines). Therefore there is a reduction in the efficiency of gas-operating setups by 2…3 % [3, 4] and a sufficient increase in the gas consumption.

Conclusions. Household gas pressure stabilizers contributes to gas fuel saving. Oscillations in the gas pressure in the tools of ±10 % have almost no influence on the efficiency of the tools and thus provide their best possible performance and efficiency. If there are stabilizers, gas-opertign setups operate at a gas pressure $P_г$ similar to the nominal one $P_{ном}^{приб}$, i.e. at a maximum efficiency. At the same time if there are no stabilizers, the setups operate at an exceedingly low pressure up to a minimum acceptable pressure before the tool $P_{\min}^{приб}$, i.e. at a minimum efficiency.

As the results of the study suggest [6], an increase in the gas pressure before the tools from $P_{\min}^{приб}$ to $P_{ном}^{приб}$ increases the efficiency of gas-operating setups by 2…3 % and thus provides sufficient gas fuel saving.

Therefore the use of two-step systems of gas supply with household stabilizers of gas pressure is a viable alternative to existing systems of gas supply and opens up significant resources for reducing material and economic costs of gas distribution and supply systems of towns.

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