Method of Choosing Energy Carriers for the Needs of Power Supply of Settlements

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Abstract: Today country level of the gasification does not exceed 70% for several reasons. Firstly, such areas as the Far East, Eastern Siberia and the northern part of Western Siberia are difficult to access. Secondly, the gas pipeline located next to settlements does not always guarantee affordable gasification of the area. Larger consumers benefit from liquefied gas. The article suggests methodological recommendations for choosing rational gas supply schemes for consumers. Ensuring the proper level of gasification of the country will improve, and in some areas create, energy infrastructure, ensure economic growth in the regions, improve the ecological situation, and also partially solve problems with overpopulation in the central regions of the country through the active development of remote territories of the Russian Federation [1, 2, 3]. Thus, the issue of gasification of the Russian Federation does not lose its relevance to this day. A promising direction is development of the gas supply in rural areas. The weak infrastructure of the countryside strongly inhibits the economic development of the country as a whole. The proper level of gasification will ensure the creation of industries that do not require powerful energy sources and a large number of service personnel.

1. Introduction
The problem of gasification arising from the choice of the gas supply system for a settlement, possible ways to solve this problem are revealed in the studies of many scientists [4÷8 and others]. Nevertheless, many aspects of the country’s gasification require more detailed analysis since they are based on the technical aspects in the design of the gas distribution systems and, to a lesser extent, touch upon issues of the economic specifics of the gas supply to settlements and remote industrial facilities. A significant amount of research is devoted to the comparative analysis of energy supply options and assessment of their economic profitability. In particular stand out studies [9÷16]. However, most of these studies consider only the problems arising in the design of energy-saving systems and, only indirectly, raise issues related to the choice of energy carrier. Hence the need to develop a method of choosing an energy carrier for the needs of energy supply to settlements. The choice of scales and areas of application of various energy resources (including gas fuel) in each case requires an economic comparison of possible options, which are, as a rule, complex energy supply options and require taking into account the energy balance for all consumers of the settlement.

To solve the problem, we use the principle of variant comparisons. As a basic option for the energy supply of cities in the region, we will adopt gasification with the natural gas. Alternatively, gasification with the liquefied gas. At the same time, we believe that the latter is used in apartment
conditions only for cooking process and for heating water for household needs. Industrial load, as well as the load on heating, ventilation of consumers remain on the switching fuel.

2. Materials and Methods
The specific reduced costs in gasification with natural gas will be equal to:

\[ M_{ng}^{gas} = M_{ng} \cdot q_g + M_{ur,ng}^{gas}, \]

where \( M_{ng} \) is the trailing expenditures for the natural gas, $\cdot$(ton of conventional fuel)\(^{-1}\); \( q_g \) is the specific consumption of the gas in urban areas, t.q.y. (quarter year); \( M_{ur,ng}^{gas} \) is the specific costs to the natural gas supply system in urban settlements, $\cdot$(quarter year)\(^{-1}\).

The specific reduced costs in the supply system in urban settlements with replaceable fuel (liquefied gas, fuel oil and coal):

\[ M_{LPG,SF}^{pow} = M_{LP} \cdot q_g + (C_{SF} + M_{SF}) \cdot \left( q_g - q_g^c \right) \eta_{gas} + M_{ur,LPG}^{gas}, \]

where \( M_{LPG}, M_{SF} \) are the district trailing expenditures for the liquefied gas and solid fuel (or oil fuel), $\cdot$-ton\(^{-1}\); \( q_g^c \) is the specific consumption of the gas fuel for cooking process in urban conditions, fuels\cdot(quarter year)\(^{-1}\); \( C_{SF} \) is the costs of coal (oil fuel) delivery and operation of heat generating plants on replaceable fuel, $\cdot$(t.q.y)\(^{-1}\); \( \eta_{gas}, \eta_{df} \) are the efficiency coefficient of heat-generating installations on gas and solid fuels; \( M_{ur,LPG}^{gas} \) is the unit costs in the liquefied gas supply system of urban settlements, $\cdot$(quarter year)\(^{-1}\).

Savings from the use of the natural gas in the intracity heating system:

\[ E_{ng} = M_{LPG,SF}^{pow} - M_{ng}^{gas} = M_{gds} + M_{gpb}, \]

where \( M_{gds} \) is the specific reduced costs in the gas distribution station (GDS), $\cdot$(quarter year)\(^{-1}\), \( M_{gpb} \) is the specific reduced costs in the gas pipelines branches, $\cdot$(quarter year)\(^{-1}\).

Since the connection of urban settlements to the gas lateral pipelines is carried out, usually through individual gas distribution stations, the unit cost of the GDS can be determined by the formula:

\[ M_{gds} = M_{gds} \left( n_{gas} \right)^{-1}, \]

where \( M_{gds} \) is the reduced costs per GDS, $\cdot$-year\(^{-1}\); \( n_{gas} \) is the average number of apartments in one city.

To identify the geometric parameters of the regional gas supply system, we use the calculation model (Figure 1). According to Figure 1 average distance between cities in the region:

\[ B = A \left( \frac{N_{gas}}{n_{gas}} \right)^{1/2} = \left( \frac{F \cdot n_{gas}}{N_{gas}} \right)^{1/2}, \]

where \( A \) is the size of the region, km; \( N_{gas} \) is the total number of apartments in the cities of the region; \( F \) is the area of the region, km\(^2\).

The number of cities connected to one tap:

\[ N_{gpb} = \left( \frac{F \cdot n_{gas}}{N_{gas}} \right)^{-1/2}. \]
Figure 1. Calculation model of the regional gas supply system.

The number of apartments supplied with the gas from one outlet [3,17]:

\[ n_{gpb} = \ell \left( \frac{n_{gas} \cdot N_{gas}}{F} \right)^{1/2}. \]  \hfill (7)

Costs in the gas pipelines branches:

\[ M_{gpb} = (a + b \cdot d) \cdot \left( \frac{n_{gas} \cdot N_{gas}}{F} \right)^{1/2}. \]  \hfill (8)

where \( \ell \) is the length of the gas lateral, km; \( a, b \) are the cost indicators of 1 km of a gas pipeline.

The initial pressure in the gas pipeline outlet corresponds to the calculated gas pressure in the main pipeline at the point of connection of the outlet. Interpreting bends as the gas pipelines that carry only a traveling load, the calculated gas flow rate can be determined by the formula:

\[ Q_{est} = \gamma \cdot Q_{gas} = \gamma \left( q_{g} \cdot n_{gpb} \cdot K_{h}^{max} \right), \]  \hfill (9)

where \( \gamma \) is the coefficient taking into account the number of branches urban GDS; \( Q_{est} \) is the gas consumption at the start of the gas lateral; \( K_{h}^{max} \) is the weighted average coefficient of hourly maximum gas consumption for the year:

\[ K_{h}^{max} = \left( K_{h}^{max} \right)_{c} \cdot \frac{g_{c}}{g_{gas}} + \left( K_{h}^{max} \right)_{bh} \cdot \frac{g_{bh}}{g_{gas}} + \left( K_{h}^{max} \right)_{heat} \cdot \frac{g_{heat}}{g_{gas}} + \left( K_{h}^{max} \right)_{ind} \cdot \frac{g_{ind}}{g_{gas}} = \sum_{i=1}^{n} \left( K_{h}^{max} \right)_{i} \cdot \frac{g_{i}}{g_{gas}}. \]  \hfill (10)

where \( \left( K_{h}^{max} \right)_{i} \) is the hourly maximum coefficient for the gas consumption for cooking process, household and industrial needs; \( g_{i} \) is the annual gas consumption for the relevant needs in urban areas, t.q.y. (quarter year).

Substituting (10) and (11) into equation (9), we have:
where \( P_{\text{int}} \), \( P_{\text{fin}} \) are the initial and final pressure in the gas pipeline outlet, MPa (abs), then equation (8):

\[
M_{gpb} = \left( \frac{n_{\text{gas}} \cdot N_{\text{gas}}}{F} \right)^{1/2} \left[ a + b \left( \frac{3.36 \cdot 10^{-3} \cdot (\gamma \cdot q_{g} \cdot K_{b}^{\max})^2 \cdot \ell^3 \cdot \frac{n_{\text{gas}} \cdot N_{\text{gas}}}{F}}{P_{\text{int}}^2 - P_{\text{fin}}^2} \right)^{0.19} \right].
\]

Substituting both into the initial equation and solving the latter with respect to \( \ell \), we obtain the necessary equation for determining the maximum length of the gas lateral:

\[
\ell = \left[ \frac{M_{\text{ng}} - M_{gpb} \cdot \frac{a}{n_{\text{gas}}} \left( \frac{n_{\text{gas}} \cdot N_{\text{gas}}}{F} \right)^{0.5}}{b \left( \frac{3.36 \cdot (\gamma \cdot q_{g} \cdot K_{b}^{\max})^2 \cdot 10^{-3}}{P_{\text{int}}^2 - P_{\text{fin}}^2} \right)^{0.19}} \right]^{0.84}.
\]

Denote by \( \ell_0 \) is the remoteness of the city from the main gas pipeline of the natural gas. The expediency of gasification of a settlement with natural gas is determined by the condition \( \ell_0 \leq \ell \). Otherwise, the settlement is advisable to gasify with the liquefied gas. When conducting specific technical and economic calculations, it is allowed to use enlarged energy and economic indicators. The solution of the problem of choosing a source of the gas supply for rural settlements is presented in [17,18]. The high-intensity development of the gas transmission system requires solving the problem in a dynamic approach. At the same time, the feasibility study of gasification of consumers is relevant: at the first stage (in the absence of the gas network) gas supply on the basis of liquefied natural (LNG) or liquefied hydrocarbon (LPG) gases, at the second stage - switching of consumers to gas network as the reference gas is connected point to the gas pipelines [19]. At the gas fuel consumption points, evaporators for regasification and storage tanks with the calculation of the seven-day gas reserve are installed. After evaporation, the gas is supplied to the reduction points to reduce pressure, where it enters to the gas distribution network in the traditional way.

Capital costs for the option of supplying consumers with liquefied natural gas, rubles, are determined by the following ratio:

\[
CL_{\text{LNG}} = CL_{s} \left( \sum A_{s} \cdot n_{s} \right) + CL_{t} \left( A_{t} \cdot n_{t} \right) + CL_{a} \left( \sum A_{a} \cdot n_{a} \right) + CL_{gausf} \left( \sum A_{\text{gausf}} \cdot n_{\text{gausf}} \right),
\]

where \( CL_{s} \), \( CL_{t} \), \( CL_{a} \), \( CL_{gausf} \) are the capital investments in the source of the gas supply, in transport, in the liquefied gas storage facilities and gasifiers, rubles, which include the cost of equipment and the costs of commissioning and construction and installation works; \( n_{s} \) is the required number of the road tankers; \( n_{t} \) is the number of liquefaction complexes; \( n_{a} \) is the required number of storages is determined from the accounting of the seven-day supply of LNG for one object.

Let us give a mathematical model for the LNG supply option with the subsequent transfer (after \( t_0 \) years) to the natural gas network:
\[ M_{\text{LNG,NG}} = C I_{\text{LNG}} + Y_{i_{\text{ser}}} \cdot CO_{\text{LNG}} + \alpha \cdot (K_{\text{NG}} - L_{\text{LNG}}) + (Y_{i_{\text{ser}}} - Y_{i}) CO_{\text{NG}}. \]  \hspace{1cm} (15)

Equating the objective cost functions, we find the limiting distance \( \ell_{\text{lim}} \) at which consumer gasified with the liquefied natural gas should be transferred to the network gas:

\[ \ell_{\text{lim}} = \frac{(CO_{\text{LNG}} - \frac{\alpha}{\eta} \cdot Q_{\text{lim}}) \cdot (Y_{i_{\text{ser}}} - Y_{i}) + \frac{L_{\text{LNG}}}{(1 + E)^h}}{CO_{\text{NG}} \cdot (Y_{i_{\text{ser}}} - Y_{i}) + \frac{C I_{\text{NG}}}{(1 + E)^h}}. \]  \hspace{1cm} (16)

where \( L_{\text{LNG}} \) is the liquidation (residual) cost of supply systems for the liquefied natural gas; \( t_{\text{ser}} \) is the service life of the gas supply system;

The economic efficiency of converting gas supply systems is determined by the difference in costs:

\[ Ef = M_{\text{NG}} - M_{\text{LNG,NG}}(\ell, t_{i}) \]. \hspace{1cm} (17)

3. Results

1. The value of the annual gas consumption of the settlement significantly affects \( \ell_{\text{lim}} \). For example, with a population density of 6 people/ha and annual energy consumption 100 (MW·h)-year\(^{-1}\) and 1500 (MW·h)-year\(^{-1}\), the difference in the values \( \Delta \ell_{\text{lim}} \approx 87.6\% \). As follows from the results analysis, with annual gas consumption of a settlement of 100 (1500) MW and a population density varying within 5-6 people-ha\(^{-1}\), if there is the natural gas in the power supply reference point, the area of its reasonable use varies from 0.80 to 1.75 km (from 23.20 to 28.40 km). Consumers remote from a long distance power supply point should be gasified with liquefied gas. In the absence of a network of the natural gas, gasification of facilities can be provided only with the liquefied gas. At the same time, it is possible, as the gas supply distribution system develops, that some consumers located at an appropriate distance from the power supply reference point will be transferred from the liquefied gas to the grid natural gas.

2. With the increase in the period of remoteness of the gasification of the support station, the possibilities of converting gas supply systems are significantly reduced (that is, the zone for switching consumers from liquefied to natural gas is reduced). So, for example, if a power supply reference point receives grid natural gas after 10 years (an annual consumption of 1000 (MW·h)-year\(^{-1}\) for natural gas, it is advisable to transfer consumers remote from the reference point to a distance of 20 km. If the remoteness of the gasification of the support point is commensurate with the service life of the gas supply system (25 years), the transfer of consumers from liquefied gas to the natural gas network is inadvisable at any distance from the power supply reference point.

3. Population density has a negligible effect on value \( \ell_{\text{lim}} \). For example, with annual energy consumption 1000 MWh·year\(^{-1}\) and population density \( q_1 = 5 \) people-ha\(^{-1}\) and \( q_2 = 6 \) people-ha\(^{-1}\) the difference of values \( \Delta \ell_{1,2} \approx 41 \% \). As an example, table 1 provides a numerical interpretation of equation (17) for settlements with annual energy consumption 1500 (MW·h)-year\(^{-1}\) with a population density of \( q = 6 \) people-ha\(^{-1}\) [3].

The use of hydrocarbon resources and their products is possible for all items with the exception of lighting, in contrast to renewable energy sources [20]. Solar energy allows the production of electricity, but at the present time it is quite expensive process (with the variant of the main source of energy), wind energy is used only for generating electricity and has serious limitations related to the geographical location of the consumer. At the moment, in Russia only gas fuel and electricity are universal sources, the rest have limited scope and a pronounced impact on the environment [21].
Table 1. Cost-effectiveness conversion of the gas supply systems.

| Gasification term natural gas network, years | 5   | 10  | 15  | 20  | 25  | 30  |
|---------------------------------------------|-----|-----|-----|-----|-----|-----|
| Economic effect, %                          | 24.45 | 15.70 | 9.26 | 5.48 | 5.11 | 3.01 |

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