<RISKS OF GAS-FIRED COMBINED CYCLE HEATING IN THE DOMESTIC AND COMMERCIAL SECTOR>

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ABSTRACT

Today we witness development of decentralized heat and electricity supply schemes development. The experts however have not found adequate answer to the question “What are major consumer risks associated with decentralized gas-fired combined cycle energy supply?” At the same time both gas supplier and gas consumer need to know what investment will in the best way provide for safe and reliable gas supply of industrial, commercial and domestic sectors. Clear approach to gas supplier and gas consumer risk forecast and relevant model will be helpful here. First we shall analyze prospects of gas-fired central and decentralized domestic and commercial heating long-term development and then make adequate forecast of probable risks. That is we shall seek to answer the question “What gas equipment and in what quantity will consumer need to provide for socially acceptable energy safety?”

The paper describes methodology of monitoring risks in heat production by small capacity gas-fired units. The paper includes the following sections:

- Factors determining priority gas use in industrial, commercial and domestic sector;
- Concept of risk associated with heat and power production by gas-fired small capacity units in the commercial and domestic sectors;
- Efficiency and risks of decentralized heat and power production, expected demand for gas-fired small capacity units and its satisfaction.

The paper also presents some findings of research of energy risks associated with small gas-fired combined cycle units operation in the Russian Federation.
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1. FACTORS DETERMINING PRIORITY GAS USE IN INDUSTRIAL, COMMERCIAL AND DOMESTIC SECTOR

The below listed questions are important for gas consumers and for gas suppliers:

1. Gas share in the fuel and energy balance for consumer heat and energy supply and this share variation outlook?

2. What strategy of gas utilization heat and power energy consumer in the house of tomorrow will choose? (Here we mean decentralized and centralized strategy of heat, hot water and power energy supply).

3. What will be energy and ecological risks at heat and power energy production on small-scale (micro-) and large-scale (macro-) of gas-to-power conversion units?

4. What will be the trends in gas utilization and demands in gas equipment for decentralized and centralized heat, hot water and power energy production in future?

We should understand what investments in gas equipment will be most effective. For this a risk forecast model is necessary. Our aim is adequate forecast of “What gas-using equipment consumer will apply in future and how many such units will be necessary?”

To assess expected gas consumer and gas supplier risks we should remember that mankind history goes 1.5-2.5 million years back. Global changes of earth surface, ocean and climate are characterized by big cycles with duration from 10-20 thousand years to 500-1100 thousand years and longer. Global natural disasters (earthquakes, tsunami, hurricanes, downfall of cosmic bodies), registered during the period of 1000-10000 years, brought irreversible damage and deaths on limited territories with probability of $5 \times 10^{-6} - 10^{-7}$ cases annually. Increased mankind abilities to resist natural and man-caused threats (due to capability to provide itself with necessary amount of energy) created favorable situation for reduction of irreversible damage probability from mentioned above disasters.

For the time present we are at the stage of growing gas-to-fuel and energy production demand. This trend is expected to continue for about 100 years. Gas demand will grow until alternative energy sources appear. According to experts’ forecasts natural gas explored reserves will be sufficient for consumers’ needs until the end of 21st century. Though because of production, transportation, and distribution problems the gas price may become too high for the consumer. In such situation consumer preferences may shift from gas to alternative energy.

That is why gas consumption and gas-using equipment demand forecasts for the nearest hundred years are needed.

Acceptable collective risk in commercial and domestic heating by gas-fired combined cycle units is equal to society-accepted collective risk. For Russia accepted collective risk values lie in the interval of $10^-6 - 10^-8$ of probable deaths per one inhabitant of the region per one year of one gas unit operation. This practically achieved index complies with the most strict social requirements and provide for reliable and safe operation of gas units. Moreover this index is by several levels higher than standards recommended by International Atomic Energy Agency (IAEA) for first contour equipment of nuclear power stations. In the context of gas prices variation gas equipment application for heat, hot water and steam supply of commercial and domestic sector of Russia provides for unit costs reduction by approximately 2,0-4,8 times per standard unit of gross national product. Major factors determining priority use natural gas for industrial, commercial and domestic heating up to 2050 are as follows:

- Comparatively low fuel consumption for heating of industrial, commercial and domestic facilities;

- High flexibility of heat production output, especially at small capacity units;
- Not very strict limitation of technological parameters providing for operation of the gas supplier – gas consumer system;

- Compactness of gas units which allows to shorten construction of heating facilities by at least 30% as compared to coal-fired heating boilers;

- Other positive engineering and economic aspects of gas equipment manufacturing, maintenance, operation, etc.

This and other factors provide for competitive advantages of gas-fired heating applications in commercial and domestic sectors, which is due improved efficiency, reliability, installed capacity operation efficiency, etc. Besides gas-fired heating equipment provide for lower pollution from combustion, heat emissions, etc. Compared to coal-fed equipment gas use heating unit are by 10-1000 times less contaminating.

Today the concept of absolute safety does not adequately comply with laws of technosphere development in the regions. Safety and risk indices are probabilistic in their essence. Only systems without storage energy are failure-risk-free. For the majority of gas-fired heating facilities failure probability and risk indices are finitesimal. We can speak only about risk reduction or optimization, failure probability decrease, and failure damage mitigation. Investments are required to provide for safe operation of equipment, but after certain level the resultant effect does not justify the price. In the 21st century safety of gas units will be less determined by technical, than by economic and social preferences. In general risk dependence on economic strategy of gas unit operation is of statistic nature. This explains necessity to develop approach to gas consumer and gas supplier risks assessment. The developed approach will underlay optimization of heating with gas and provide answers for the above formulated questions.

2. CONCEPT OF RISK ASSOCIATED WITH HEAT AND ELECTRICITY PRODUCTION BY GAS-FIRED SMALL CAPACITY UNITS IN THE COMMERCIAL AND DOMESTIC SECTOR

Promgaz approach to forecasting risks associated with natural gas utilization is based on the following two guidelines:

- Prevailing importance of providing for energy safety of the whole country and its individual regions;

- Improvement of Gazprom activity efficiency provided compliance with social and legal norms.

For preparation of risk forecasts OAO Promgaz develops adequate models of energy and ecology risks of electricity and heat production by gas-fired small capacity units. These units implement different thermodynamic gas energy conversion cycles. Gas-team cycle is expected to prevail in the mid- and long-term.

Statistic models and concept of natural gas use are formulated on the information basis, specific for each region of the Russian Federation. These models are verified afterwards. For construction of models we use inquiries of experts from Russian gas companies and other necessary information.

Developing our model we conditionally divided all territories (countries) into five groups:

The first group contains territories characterized by high density of population, for example, the Moscow region, where exists developed gas networks and electric power grids, and advanced industry.

The second group contains territories and countries where exists advanced industry, but own gas fields and other fuel recourses are practically absent.
The third group unites territories and countries where exists advanced industry, high density of population and where heat and electricity are also supplied from other sources, for example, from nuclear power stations. The share of gas in domestic sector of such territories is small yet.

The fourth group includes regions with low density of population, large-scale gas fields and excess of gas fuel.

The fifth group of territories includes regions with low density of population and without producing gas fields, where rural population prevails and industry is not yet well developed.

At the same time the territories of listed groups were divided to two typical for every country or region sub-groups – urban and rural territories. All groups were analyzed from the point of view of gas supplier’s risks and taking into consideration the climate peculiarities (average annual temperature, winter period, etc.).

The second circumstance taken into consideration at model construction is fuel and energy recourses on all territory of Russia

3. EFFICIENCY AND RISKS OF DECENTRALIZED HEAT AND ELECTRICITY SUPPLY OF INDUSTRIAL, COMMERCIAL AND DOMESTIC SECTORS, FORECASTS OF SATISFIED CONSUMER DEMAND FOR GAS-FIRED HEATING EQUIPMENT

Integral demand, expected risks, expected satisfaction of domestic consumer demand for gas-fired heating equipment are shown in the Figure 1 below.

![Figure 1: Expected consumer demand satisfaction](image)

The curves in picture are plotted as based on the results of undertaken questionnaire survey. The scheme of questionnaire survey implementation is presented in Figure 2 below:
Consumer location
A – country with own gas reserves
B – country without gas reserves or supply
C – country without gas reserves but with gas supply
B1 unrestricted gas supply; B2 limited gas supply B21 gas supply covers no less than 95% of demand, B22 gas supply covers no less than 90% of demand

Is consumer located in the country with most favoured conditions for gas supply?
Is consumer located in the country with scarce gas supply?
Is consumer located in the country providing preferences for gas exports?

Is consumer located in the region:
A with developed gas network for unrestricted gas supply
B with developed gas network and restricted gas supply
C without gas network and with bottled LNG/CNG supply
D without either gas network and or bottled LNG/CNG supply

Gas consumption terms: Consumer gas demand:
A constant within the year and unrestricted
B seasonal and in restricted volumes
C non existent

Gas utilization terms:
A - Consumer uses highly automated and efficient equipment for gas-to-heat conversion (questions A1-A10 about equipment)
B - Consumer employs gas utilization quality management system (B1-B10)
B- Consumer applies resources saving technologies (questions C1-C10 about gas reduction energy utilization)

Figure 2. Algorithm for questionnaires and surveys organization
For implementation of abovementioned estimations OAO Promgaz offers algorithm based on cost-efficiency statistical analysis methods and energy risks probabilistic analysis. The essence of represented algorithm applied to the problem of gas consumption for centralized and decentralized heating in domestic sector is explained by the algorithm for expert assessment of gas use efficiency in domestic heating. For this purpose a multifactor statistic model of the type presented below is suggested:

$$X_{ijkm} = \mu + R_k + A_i + B_{ij(i)} + C_m + AC_{im} + BC_{mj(i)} + \epsilon_{ijkm},$$

$X_{ijkm}$ - stands for efficiency (or risk) value (or other stochastic variable characterizing answers to the questions in questionnaires, for example, what will the resultant benefits (damage) be provided the given scenario of central/decentralized heating; $\mu$ - average risk value derived from multiple enumerations; $R_k$, $A_i$, $B_{ij(i)}$, $C_m$ - externalities' impact factors within the selected central and decentralized gas heating scenario development, which account for specificity of gas supply object in terms of its location, operation period, operation experience, servicing, modernization, including personnel incorrect actions situations, etc., $k$, $i$, $j$, $m$ - determinants of quantitative and qualitative levels of influences.

Then using absolute random block planning of risk model we undertake variance analysis of actual determinants of impacts' significance. Optimum strategy of decreasing risk of the scheduled central and decentralized heating development is determined in relation to the limited number of impacts. Say, such factor as ownership of gas-to-heat conversion equipment for domestic sector.

Risk related to equipment operation terms (the method or an array of methods selected for gas-to-heat conversion) can be calculated on the basis of known mathematical statistics criteria. Then gas company managers will select and prove optimal variant of central and decentralized heating development events in the following coordinates: risk of the region energy safety - terms of domestic gas supply-economic profit. Thus general scheme of gas supply could be determined, optimization factors included.

Using collected data we have determined that today in the regions there exists an unsatisfied demand for central and decentralized gas heating. The questionnaire survey revealed as sustainable trend preference of decentralized heating by urban consumers at the territories of the 3rd and 4th classes.

Consumers' preferences analysis as for questionnaires feedback data considering factors influencing heat and fuel process in different regions of Russia as shown the following:

1. For Russian territories of the first qualification group, where gas main pipelines grid in small towns and rural areas is developed, the consumer prefers decentralized heating. In the cities of these regions consumer is still prefers centralized heating. However, forecasts concerning price increase of heat from big heat and power stations and gas boiler houses transportation lead to emerging of a new trend. It means that in some regions of Russia, especially annual amount of days with average minus temperatures exceeds 150, urban consumer already prefer decentralized scheme of gas and hot water supply. This preference will grow until 2020, and with confidence probability of 76% will be kept out of the limits of stated period.

2. For Russian territories of the third qualification group, where gas fuel mainly supplied as a liquefied gas for cooking in domestic sector, consumer at present use for heating other fuels: coal, masut (heavy fuel oil), and electricity. However checking statistical hypothesis concerning possible growth of liquefied and compressed gas consumption in domestic and commercial sector is shown that such growth is expected in 2010-2030. According to calculations' results hypothesis of liquefied gas consumption growth for decentralized heating is statistically significant with 92% confidence probability. It underlines that liquefied gas consumer in distant areas in future will need high-performance gas-to-heat energy conversion equipment.

Trends of centralized and decentralized heating (based on gas) provision are pointed out to expected growth of gas consumption for about 40% (every 10 years up to 2020) in all regions of Russia. Also it is expected that consumer and supplier of gas for heating will press toward risks
diversification. Risks analysis is pointed out that regional consumer needs high-automated plants of gas-to-power and heat conversion of small capacities. Consumer of the future will also need high-performance gas units for water heating and steam production. At the same time, consumer prefers units with completely automated operation (so-called unmanned production technique). Calculations showed that with 95% probability until 2020 it is expected annual 10% growth of demand to small capacity equipment for gas energy conversion.

In the regions if Russia, especially in European part, where the share of nuclear energy is noticeable, it is expected development of advanced high-performance combined-cycle plants consolidating advantages of nuclear stations and steam-gas turbines. In this connection in rural area will grow the demand for small autonomous gas units, for example, for autonomous modular gas boiler houses with installed capacity from 10 kW to 3 MW.

However statistically significant forecast shows, that gas demands of urban consumers preferring decentralized scheme of heating will be satisfied only till 2013-2014. For rural area demands in centralized heating will be met in Russia not earlier 2020.

CONCLUSIONS

If we consider the long period of risks forecasting for heating gas by gas-using equipment in commercial and domestic sector, satisfaction of gas demands for consumers of tomorrow, we could acknowledged received 30-40% precision of forecasts as quite satisfactory. At the same time it is possible to improve forecasts precision and risks assessment by number of territories qualification groups increasing and, simultaneously, more detailed consideration of its' characteristic indices. These circumstances obviously make experts' work more complicated and difficult, but at the same time forecasts precision can be increased manifold.

Demands expectations and equipment life cycle analysis for centralized and decentralized heating on gas fuel show that this sector of gas industry has the trend of accelerated growth in the field of new improved gas energy conversion units and in the field of demand growth to such kind of equipment as well. That is why we can expect up to 2030 investments increase in development and production of gas-to-heat conversion units and other domestic sector requirements. It worth to mention that demands acceleration on innovative production, such as effective gas-using units for domestic sector, will take place subject to foreground development of decentralized heating scheme in the regions of Russia. As calculations show, it is expected demand jump to LNG and CNG fuelled units. It means that in the nearest future the problem of safe transportation and long-term storage of liquefied and compressed natural gas should be solved, for example, by using safe cryogenic tanks.

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Figure 2: Algorithm for questionnaires and surveys organization