

Analysis and optimization of indicators of energy and resource consumption of gas turbine and electric drives for transportation of hydrocarbons

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Abstract. The paper presents the results of the analysis of statistical indicators of energy and resource consumption in oil and gas transportation by the example of one of the regions of Russia. The article analyzes engineering characteristics of compressor station drives. Official statistical bulletins on the fuel and energy resources of the region in the pipeline oil and gas transportation system were used as the initial data.

1. Introduction

Main oil and gas pipelines are important components of the energy supply system of the Russian economy. Therefore, the problem of reliability and efficiency of their functioning is considered as one of the priority. Sufficiently significant facilities in solving this problem are gas turbine and electric drive systems for pumping and compressor stations of main pipelines.

In the current practice of operating domestic main oil pipelines (MOP), the drive of all pumps of oil pumping stations (OPS) is electric, and in the system of main gas pipelines (MGP), the drive of gas compressor units of compressor stations (CS) is mostly ϕ gas turbine.

2. The role of energy consumption and resource consumption in the transport of oil and gas

Russia has a large under-utilized energy-saving potential, which, as far as its ability to solve the problem of ensuring economic growth of the country is comparable to the growth in production of all primary energy resources.

Lack of energy can be some factor in restraining the economic growth of individual countries. According to analysts, until 2020, the rate of reduction in energy intensity in the absence of a coordinated state policy on energy efficiency can slow down sharply. This could lead to an even more dynamic growth in the demand for energy resources within the country. There are enough oil and gas reserves in Russia; however, an increase in hydrocarbon production and the development of transport infrastructure require significant investments.

In the paper, the analysis and estimation of statistical indicators of energy and resource consumption in oil and gas transportation in the Tyumen region is presented as an example. To achieve this task, statistical bulletins were used as the initial data: cost of production and sales of products in Tyumen region for 2015-2016; use of fuel and energy resources in Tyumen region in the pipeline oil and gas transportation system for 2015-2016.



The total energy consumption of Russia in recent years has been about 990 million tons of fuel equivalent. When bringing the introduction of energy-saving and energy-efficient equipment to the level of the EU member countries, energy consumption would decrease to 650 million tons of fuel equivalent. In other words, about 35% of energy is lost.

Barriers to the development of energy conservation and energy efficiency in any country can be divided into four main groups:

- lack of motivation;
- lack of information;
- lack of experience in project financing;
- lack of organization and coordination.

There are two ways to solve the emerging problem of increasing energy and resource efficiency:

- the first is an extremely capital-intensive way of increasing oil and gas production and constructing new power generation facilities;

- the second is much less expensive, associated with ensuring economic growth in the country through increased efficiency in the use of fuel and energy resources.

It should be noted that in practice a complex of the first and second variants is necessary with an undoubted priority of energy efficiency.

Systematic work in the field of energy conservation and energy efficiency in various sectors and spheres of the Russian economy began after the adoption of the Federal Law of the Russian Federation of 23.11.2009 No. 261-FZ "On energy conservation and on improving energy efficiency and on introducing amendments to certain legislative acts of the Russian Federation".

In 2010, the Ministry of Energy of Russia jointly with CJSC "APBE", LLC "CENEF" and FGA "REA" developed the State Program of the Russian Federation "Energy saving and energy efficiency improvement for the period until 2020" ("SPEE-2020"), which was approved by the Government of the Russian Federation on 21.10.2010 and by the decree of the Government of the Russian Federation No. 2446-r dated 27.12.2010.

The program is designed to be a tool to address the massive task of reducing the energy intensity of GDP by 13.5% by 2020 through energy-saving measures.

To realize the measures prescribed in the Program, it is necessary to attract funding from various sources, since program activities are inconceivable without analysis and cost estimation [1].

It is also worth mentioning that the project "Energy strategy of the Russian Federation for the period until 2035" sets the task of developing new highly efficient gas pumping units with gas turbine and electric drives as well as more sophisticated domestic construction materials for the creation of these units. [2]

3. Assessment of the efficiency of gas turbine and electric drives

A significant proportion of accidents on main oil (MOP) and gas pipelines (MGP) is accounted for by oil pumping stations (OPS) and compressor stations (CS), respectively.

With existing backups on MOP and MGP in the absence of cascading failures, failure of one element does not lead to failure of the entire system, but only worsens the efficiency of its operation. Reliability problems can be solved by both rational use and distribution of costs for maintenance and development of the system, as well as costs for backups, and by increasing these costs. Therefore, the problem of reliability here is a technical and economic problem.

In recent decades, Russia has pursued a policy of establishing "parity" of domestic prices for electricity, liquid fuel and fuel gas, which to some extent affects the cost-effectiveness of energy resources for their consumers, in particular, for the OPS and CS drive systems of the main oil and gas pipelines.

The choice of a rational drive system of MGP CS is the subject of numerous studies and justifications, which do not allow one to make unambiguous decisions so far. However, a number of known causes and circumstances predetermined by now a very clear relationship between the types and expediency of using MGP CS gas turbine (GGPU) and electric (EGPU) drives.

The competitiveness of gas turbine and electric drives depends primarily on CS power supply conditions. Usually CS with electric drive GPU are built on sections of gas pipelines passing through areas with a developed power system that has reserves of electrical power. Selection of the parameters and type of the compressor GPU drive is carried out on the basis of technical and economic calculations. To calculate the reduced costs for the selected options, enlarged technical and economic indicators are used obtained as a result of experience in the construction and operation of main gas pipelines.

An important argument in favor of EGPM is high efficiency factor of electric motors (about 0.95) compared to low efficiency factor of gas turbine motors (0.25-0.29). However, it is more appropriate to consider the energy utilization efficiency factor. In this case, when electric drive stations are supplied with power from TPP with an efficiency of 0.3-0.35 through the electrical distribution systems, the energy efficiency factor of the electric drive and gas turbine CS are practically equal [3].

Many well-known technical, energy, environmental, reliability, regulatory, economic, price and other characteristics and indicators, as well as advantages and disadvantages of both systems of GPU drives, are so different or converging that in the absence of unity of approaches and opinions on the significance, priority and ranking of individual factors or groups of factors, the solution of a problem of an optimum choice of a drive system is strongly complicated. A systematic approach to the solution of the problem is needed on the basis of a scientific assessment of the significance and priority of the factors characterizing the systems of drives in question or their combinations at CS under different conditions and types of security of the energy base of their location areas [4].

The question of comparing the advantages of gas turbine and electric drive is of great importance. Large current costs for electricity due to the high tariff for it encourage replacement of the existing electric drive units for gas turbines.

Nevertheless, in a number of cases, for example, in areas with low costs for electricity, and also for a number of other reasons, it is impossible to eliminate the use of electric drive units with a number of undeniable advantages over gas turbine drives. An electric motor produced by "Electrotyazhmash-Drive" SDG2-12500-2R UHL3.1 and a gas turbine unit MS5002E produced by "Nevsky Zavod" in cooperation with GeneralElectricOil & Gas (NuovoPignoneS.pA) were compared. (Fig. 1, 2) (Table 1).



Figure 1. GTU MS5002E [5]



Figure 2. Electric motor SDG2-12500-2R UHL3.1 [6]

In this regard, it should be noted that in the domestic practice of pipeline transport of oil and petroleum products at pumping stations, the use of purely electric pumps was largely determined by the ideological significance of domestic electrification. While in the foreign practice of transport of oil and petroleum products, the gas turbine drive of OPS pumps with various power supply systems is mainly used [7].

Table 1. Comparison of the basic parameters of electric and gas turbine engines

Parameter	Electric motor SDG2-12500-2R UHL3.1	Gas turbine unit MS5002E
Power MW	12.5	32
RPM speed	3000	5714
Efficiency %	97.8	36
Weight kg	36000	93000

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In the energy aspect, the electric drive from thermal power plants and the gas turbine drive of OPS are practically equally effective.

From the economic point of view, calculation of the effectiveness of the compared OPS systems is quite routine, requiring generalization and evaluation of a large number of initial data under current conditions, previous design decisions, conditions for the future operation of the oil pipeline and foreign experience.

At the same time, it can be noted that with an unregulated electric drive of pumps, lower costs for buildings and equipment are significantly increased by the cost of constructing a power supply system. With a gas turbine drive of pumps, the composition and cost of associated equipment (installations for the selection, preparation and use of fuel) are significantly increased.

GTE in the drive of main oil pipeline pumps can be used in areas with different climatic conditions. It is preferable to use them in areas with a relatively low average annual ambient temperature, i.e. in the regions of the Far North and Siberia.

In the world practice, there are enough examples of the extensive use of gas turbine engines on main oil pipelines, including Trans-Alaska, with a length of about 1300 km in northern conditions close to Western Siberia and the Far North of Russia [12, 13].

A special place in the operation of GTE on oil pipelines takes the use of pumped fuel. Such fuels as kerosene, gasoline, diesel, associated gas and natural gas directly correspond to the requirements for fuel for gas turbines. Natural gas is efficiently used when a gas pipeline runs parallel to an oil pipeline. Associated gas can be used if it is pumped with oil. Pumped crude oil can be used after preparation in special block distillation units. After rectification of the oil, 25-30% of the wide fraction of light hydrocarbons (NGL) is obtained, and the residue (fuel oil) is pumped into the oil pipeline. The use of such system is economically advantageous in areas remote from powerful sources of electricity. Utilization of combustion products solves the problem of OPS heat consumption.

The gas turbine drive is the most economical to regulate the delivery of a pumping unit, and a controlled electric drive system is the least economical.

In the domestic practice of pumping unit drives of main oil pipelines, there are also some examples of the evaluation and use of a controlled electric and gas turbine drive. Special attention should be paid to the development of Aviadvigatel for the Sakhalin-2 project.

However, in order to fully assess the effectiveness of a particular type of the OPS drive, further technical and economic assessment is necessary, taking into account the reliability for the specific operating conditions. In areas with low cost for electricity supplied from hydroelectric or atomic power plants, electric OPS drives can be more economical than gas turbine drives. At the same time, in the conditions of frequent changes in the operation mode of the oil pipeline, the OPS gas turbine drive may be preferable [14].

A useful foreign experience in the design and construction of OPS and the linear part of the main

oil pipelines, including the experience of aboveground laying in permafrost conditions, should be taken into account in the construction of new main oil pipelines.

Total efficiency of the value-added use of energy resources in the economy (taking into account losses during extraction, transportation, etc.) by 1975, even in industrially developed countries, like the United States, was estimated at 10-15%.

In the economy of the USSR, the utilization efficiency of energy resources was roughly estimated (according to accounting data for 1985) to be 10.6%. However, even this single and very rough estimate allows us to conclude that the level of energy use in the economy of the country is much lower than it was previously assumed [8].

It has always been assumed that there are large reserves of increasing the efficiency of energy resources (energy and fuel), i.e. a component of energy saving. However, in practice the weight of the energy resources used is not estimated by their indicator (utilization efficiency), but by their share of value in the total costs of the economy.

At present, the share of energy costs in the total costs of the economy in Russia averages about 13%, and for certain regions and areas of activity (industries) it deviates up to 50%, more or less than the average. So in Tyumen region, it is about 7%.

As for the share of costs for raw materials and materials in Russia, on average, it is 2-3 times higher than the share of energy costs, and for individual industries, this difference reaches significantly higher multiplicities. This was also about 50 years ago in the USSR.

Relatively low shares of energy costs in the country's economy, as well as in the oil and gas sector, with relatively high shares of costs for stock and raw materials, do not cause much enthusiasm for energy saving and energy efficiency among the managers of these industries. But broad propaganda of energy saving often determines the need for their participation in campaigns to develop their energy-saving programs.

4. Ratio of the shares of costs for oil and gas transportation and costs for using fuel and energy resources in cost parameters

In the practice of enterprise management, continuous monitoring of energy and resource efficiency indicators is used. Comparative analysis makes it possible to assess the influence of various factors on the energy and resource consumption of production. For this research, the following parameters are of interest when analyzing the cost of oil and gas transportation: expenses for stock and raw materials; expenses for fuel and energy (based on data from the statistical bulletins of the industry in Tyumen region for 2015-2016).

A large share in the cost for production and sales of products is taken up by costs associated with the cost for "fuel and energy"; the figure reaches 1/5 of the total costs.

In the below mentioned statistical data, the dynamics of costs in 2015-2016 for the indicator "stock and raw materials" for the transportation of oil and oil products is observed, which amounted to 287.68 c.u. (2015) and 306.88 c.u. (2016), which is respectively 3% and 2% of the total costs (Table 2) [9].

Over 2015-2016, there has been a stable share of the costs for "fuel and energy" (mainly electricity) - 18%, which in monetary terms is 1,739.86 c.u. in 2015, 2,318 c.u. - in 2016.

To bring the data of Tables 4 and 5 to the state of liquidity, the following transfer scale of units of energy types in fuel equivalent (f.e.) was used:

- Electricity - 1 kWh = 0.32 kg of f.e.;
- Heat power -1 Gcal = 170 kg of f.e.;
- Fuel (gas) - 1m³ of gas = 1.13 kg of f.e.

Table 2. Pipeline transportation of oil and oil products

	2015	2016
Costs for the production and sale of products (goods and services) c.u., (%)	9,539.27 (100%)	12,816.7 (100%)
Expenses for the purchase of raw materials, stock materials, purchased semi-finished products, components purchased for production, but sold on the side without processing. c.u., (%)	287.68 (3%)	306.88 (2%)
Fuel consumption expenses. c.u., (%)	153.88 (1.6%)	125.64 (0.98%)
Energy expenses. c.u., (%)	1,739.86 (18%)	2,318 (18%)

In gas transport, a comparative cost analysis showed that for "stock and raw materials" costs are from 6.4% (6,203.65 USD in 2015) to 4.4% (4,449.38 USD in 2016). The total costs for "fuel and energy" (mainly gas) fluctuate within 11-13% (Table 3) [10].

Table 3. Pipeline transportation of gas and gas products

	2015	2016
Costs for the production and sale of products (goods and services) c.u., (%)	96,469.82 (100%)	99,370.58 (100%)
Expenses for the purchase of raw materials, stock materials, purchased semi-finished products, components purchased for production, but sold on the side without processing. c.u., (%)	6,203.65 (6.4%)	4,449.38 (4.4%)
Fuel consumption expenses. c.u., (%)	10,607.68 (10.9%)	8,804.92 (8.8%)
Energy expenses. c.u., (%)	1,952.2 (2%)	2,187.22 (2.2%)

As for the oil and gas pipeline transportation systems, there is a slightly different situation in terms of the ratio of the cost shares for "fuel and energy."

In Tyumen region, oil transportation energy consumption is 98.8% for electricity and 1.2% - for fuel (Table 4), and in gas transportation it is 70.2-70.6% for electricity and 28-29% - for fuel (Table 4) [10,11].

Table 4. Use of fuel and energy resources in Tyumen region in 2015

	Production, total	Actual expenses for production	
		Electricity, thousand kW (tons of f.e.)	Heat power, Gcal (tons of f.e.)
Oil transportation through main oil pipelines, thousand tons*km	224,822,935	3,897,130 (1,248)	43,567 (7,395)
%		98.8%	1.2%
Gas transportation through main oil pipelines, thousand tons*km	582,628,062	3,610,661 (1,248)	1,525,483 (259,318)
%		70.2%	29.8%

Table 5. Use of fuel and energy resources in Tyumen region in 2016

	Production, total	Actual expenses for production	
		Electricity, thousand kW (tons of f.e.)	Heat power, Gcal (tons of f.e.)
Oil transportation through main oil pipelines, thousand tons*km %	284,228,441	3,698,400 (1.184) 98.7%	45,961 (7,820) 1.3%
Gas transportation through main oil pipelines, thousand tons*km %	500,375,061	3,137,757 (0.992) 70.6%	1,306,560 (222,105) 29.4%

5. Conclusion

Therefore, analysis and evaluation of the data of the statistical bulletins discussed in this paper made it possible to draw a conclusion that at compressor stations of the main gas pipelines, passing through the territory of Tyumen region, the use of gas turbine engines is more expedient, since the costs for "fuel and energy" in gas transport are determined mainly by the tariff for fuel gas, which is lower than the tariff for electricity. In other regions of the country, the situation can be diametrically opposite; everything depends on the development of the infrastructure. If the region has well-developed power supply channels and its cost is not high, then the enterprises will install a GPU with an electric drive. In other cases, it will be expedient to install a GPU with a gas turbine engine. However, gas transport enterprises conduct a number of experiments on the introduction of gas distribution stations and shops equipped with electric motors, which is due to close proximity to large sources of electricity. A more comprehensive evaluation of the efficiency of an electric or gas turbine engine requires research that is more thorough. Using the technique of selecting and calculating equipment depending on the technical and economic indicators, as well as on the geographical location and resource support of each of the regions of the Russian Federation will allow obtaining optimization solutions and more efficient resource consumption taking into account regional features. All the developed measures to ensure energy efficiency and to justify the drives should take into account both the requirements of international standards, such as the international standard ISO 50001:2011, and the requirements of the Energy Strategy of the Russian Federation and facilitate the implementation of import substitution programs.

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