International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

Energy Saving and Clean Technology for Natural Gas Transporting

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***Abstract*: Sustainable development of the Arctic oil and gas deposits depends on the reliable and efficient operation of the gas transportation system (GTS), which development has great importance for industry growth. In spite of high reliability of GTS, it is necessary for such specific area, as Arctic is, to use the technology, which is safe and clean. In this paper, the major factors influencing on industrial and ecological safety of GTS are analyzed, revealed factors which impact GTS safety, and on that base measures for providing safety are proposed.**

The paper shows that use of gas-turbine engines of gas-compressor units (GCU) results in the following features: emissions of hazardous substances in the atmosphere; pollution by toxic waste; harmful noise and vibration; thermal impact on the environment; decrease in energy efficiency. It is shown that for the radical problem resolution of industrial and ecological safety of gas-transmission system it is reasonable to use gas-compressor units driven by electric motors. For such critical issue as clean and safe gas transporting in the Arctic region the gas compressor units with electrical drives has a great perspective for implementation, taking into account their serious advantages and industrial tests in Europe and USA.

***Keywords*: electric gas-compressor units, energy efficiency, environmental safety, gas transportation system, industrial safety.**

I. INTRODUCTION

Gas industry has a strategic role in the economy of Europe and the Arctic regions. About a half of total production and internal consumption of energy depends on natural gas. With the refusal of coal, the role of natural gas will only continue to grow in energy balance.

The most powerful gas transportation system (GTS) is for transportation of natural gas from places of its production to consumers. Main suppliers of natural gas are Norway, Great Britain, France, the United Arab Emirates, and Russia. The main consumers of the Russian natural gas in Europe are Germany and Italy. Fig. 1 shows the scheme of the existing gas transportation system in Europe.

Revised Manuscript Received on February 28, 2020.
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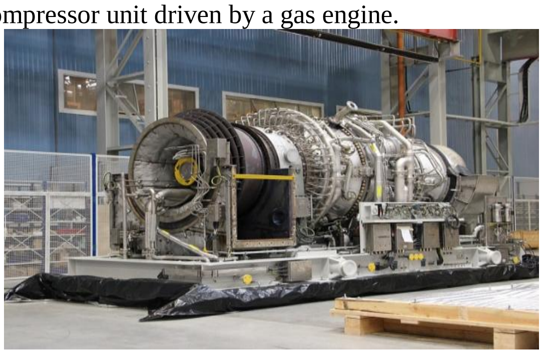
The stable development of the European countries depends on a reliable and efficient function of the gas transportation system [4, 14, 15, 21, 23]. With the high reliability of GTS, it is necessary to ensure its industrial and environmental safety. In the article the major factors influencing on industrial and ecological safety of GTS are analyzed, sources of GTS safety decreasing are revealed; measures for providing safety are proposed.

Fig. 1. Scheme of the gas transportation system in Europe

II. MATERIALS AND METHODS

A. Structure of gas-compressor units

The main elements of gas-transportation systems (GTS) are the main gas pipelines (MGP) and compressor stations (CS), which consist of compressor shops. The com-pressor shop consists of a gas-compressor unit (GCU), gas coolers, power supply system, water supply system, alarm system, fire extinguishing and room artificial climate system, connection points, shutdown safety valves, stop valves, dust collectors etc. The gas-compressor units are the largest consumers of energy resources and, are the power center of the gas transportation system. Fig. 2 (1) shows the external view of the Rolls-Royce (Great Britain) gas-compressor unit driven by a gas turbine, Fig. 2 (2) is the Siemens (Germany) electric gas-compressor unit, Fig. 2 (3) is the Caterpillar (USA) gas-compressor unit driven by a gas engine.



(1)

(2)

(3)

Fig. 2. Different types of gas-compressing units

The working body of the gas-compressing units is centrifugal superchargers (CS) which compress and transport the natural gas along the main gas pipeline. Power of centrifugal superchargers, now in use on the main gas pipelines, varies from 2.5 to 32 MW [9-11].

The following engine types are used for driving the centrifugal superchargers:

- gas turbine engines;
- electric motors;
- gas engine compressors.

More than half of the parks of gas-compressor units in Europe have the gas turbine drive. For gas turbine gas-compressor units a natural gas is used as the main fuel, which is transported in the main gas pipelines. Combustion of natural gas in a huge number at compressor stations leads to a decrease in the level of industrial and ecological safety.

B. Industrial and environmental safety of gas-transportation system

Level of industrial and ecological safety of gas transportation system objects is in a direct connection with the reliability of the system. Many of the measures directed to increase of gas transportation system reliability should be considered as a way of a decrease in risks of defeat and death of people and environment violation, i.e. safety increase.

Efficiency and safety of the gas transportation system functioning are substantially determined by ecological compatibility of work of the system main objects, one of which is a compressor station. Exactly where the greatest number of the power-intensive equipment intended for ensuring a technological process of natural gas transportation is concentrated, branched systems of technological communications function and a large number of service personnel are involved [3, 4, 17, 20, 28].

The main sources of the polluting substances are the gas-compressor units driven by gas turbines, centrifugal superchargers, oil degasser and technological processes connected with their operation.

C. Main factors of gas-compressor unit impact on environment

The main factors of the gas-compressor unit, which impact on environmental conditions:

1. emissions of harmful substances in the atmosphere;
2. toxic waste;
3. noise and vibration;
4. thermal influence;
5. energy saving problem.

1. Emissions of harmful substances in the atmosphere. These are emissions of natural gas and emissions of combustion products (exhaust gases of the gas-turbine engine). Table 1 shows parameters of technical standards of emissions of gas-compressor unit polluting substances, received experimentally.

Emission of natural gas on compressor station happens at start-up and stop of the gas-compressor unit, and also during operation with tightness violation of its main parts.

The exhaust gases are created as a result of the natural gas combustion in the gas turbine of the gas-compressor unit. They consist of:

- combustion products – nitrogen, water vapor, carbon dioxide;
- nitrogen oxides;
- carbon dioxide;
- sulphur oxides;
- hydrocarbons (including not completely burned methane);
- soot.

At combustion of the gases containing hydrogen sulfide, sulfuric and sulphurous anhydrides, not burned hydrogen sulfide are also released into the atmosphere.

Table 1. Emissions of polluting substances of gas-compressor units

Parameter	Parameter values				
Power of gas-compressor unit [MW]	2 ÷ 4	6 ÷ 8	10 ÷ 13	16 ÷ 18	22 ÷ 31
Fuel gas consumption [m3/h]	1106 ÷ 1795	1824 ÷ 2872	3077 ÷ 5051	4720 ÷ 6593	6889 ÷ 10539
Temperature of combustion products [^oK]	1113 ÷ 1270	947 ÷ 1295	1053 ÷ 1456	1130 ÷ 1456	1188 ÷ 1518
Concentration in dry combustion products:					
nitrogen oxide [mg/m^3]	35 ÷ 136	69 ÷ 202	69 ÷ 199	48 ÷ 179	50 ÷ 353
carbonic oxide [mg/m^3]	25 ÷ 82	33 ÷ 239	29 ÷ 275	48 ÷ 229	41 ÷ 441
Modified concentration:					
nitrogen oxide [mg/m^3]	50 ÷ 195	135 ÷ 490	100 ÷ 230	80 ÷ 250	50 ÷ 400
carbonic oxide [mg/m^3]	30 ÷ 130	90 ÷ 300	60 ÷ 300	80 ÷ 300	50 ÷ 500
Emission efficiency:					
nitrogen oxide [g/s]	0,52 ÷ 1,67	2,58 ÷ 6,93	2,38 ÷ 7,81	3,29 ÷ 11,8	2,91 ÷ 26,65
carbonic oxide [g/s]	0,41 ÷ 1,35	1,5 ÷ 6,66	1,81 ÷ 8	3,5 ÷ 14,5	3,59 ÷ 39,08
Specific emission on fuel gas unit:					
nitrogen oxide [g/s]	1,39 ÷ 5,42	3,75 ÷ 13,62	2,78 ÷ 6,39	2,22 ÷ 6,95	1,39 ÷ 11,12
carbonic oxide [g/s]	0,83 ÷ 3,61	2,5 ÷ 8,75	1,67 ÷ 8,34	2,22 ÷ 8,34	1,39 ÷ 13,9
Specific emission on thermal power unit:					
nitrogen oxide [g/GJ]	41 ÷ 162	112 ÷ 407	83 ÷ 249	66 ÷ 207	41 ÷ 332
carbonic oxide [g/GJ]	24 ÷ 108	75 ÷ 249	49 ÷ 174	66 ÷ 249	41 ÷ 415
Specific emission on unit of work:					
nitrogen oxide [g/kWh]	0.47 ÷ 2.31	1.48 ÷ 5.88	0.86 ÷ 2.16	0.73 ÷ 2.59	0.43 ÷ 3.92
carbonic oxide [g/kWh]	0.29 ÷ 1.22	0.9 ÷ 3.73	0.65 ÷ 2.73	0.8 ÷ 3.27	0.54 ÷ 5.12
Specific emission on gas supply unit:					
nitrogen oxide [g/thousands of m^3]	6 ÷ 114	11 ÷ 24	10 ÷ 37	8 ÷ 18	5.28 ÷ 48.99
carbonic oxide [g/thousands of m^3]	4.17 ÷ 49.22	5.40 ÷ 52.89	4.34 ÷ 32.50	9.06 ÷ 37.73	6.53 ÷ 61.23

The Directive of the European Parliament and Council 2001/80/EU specifies maximum permissible values of emissions concerning the gas-turbine engines of gas-compressor units certified before 11/27/2002 and accepted for operation before 11/27/2003:

- on nitrogen oxides of 50 mg/m3 when using as fuel natural gas with the content of inert gases no more than 20%;
- on nitrogen oxides of 75 mg/m3 for gas-turbine engines in cogeneration installations with the general efficiency more than 75%, for gas turbines in a combined heat and power plant (CHP plant) with the general average annual efficiency more than 55%.

2. Toxic waste. Gas-compressor unit has lubricating systems of the gas turbine engine and the centrifugal supercharger. hydraulic systems of the centrifugal supercharger shaft sealing which use different lubricating oil types with storage oil tanks for the engine and the centrifugal supercharger accordingly [12, 18, 19].

During work of the gas-compressor unit toxic substances are emitted from oil tanks of the gas-turbine engine and the centrifugal supercharger, from the oil degasser of the supercharger sealing system.

The toxic substances arriving from a shaft oil sealing system of the centrifugal supercharger because of pressure difference in the supercharger and the degasser, which is under atmospheric pressure are emitted in the degasser.

Toxic substances are emitted in atmospheric air from oil tanks of the gas-turbine engine and a centrifugal supercharger in which the oil heated in the engine and the supercharger circulates.

For gas-compressor units *with power up to 10 MW inclusive*, irrevocable losses of oil should not exceed:

- with stationary gas-turbine installations – 1.0 kg/h;
- with converted engines – 2.0 kg/h;

for gas-compressor units *with power more than 10 MW*:

- with stationary gas-turbine installations – 1.5 kg/h;
- with converted engines – 2.5 kg/h.

3. Noise and other types of influence. Noise pollution of the atmosphere is an operation consequence of gas-compressor units and traffic (road transport. helicopters. etc.). If noise levels exceed health protection standards. Serious problems for service personnel arise.

Gas-compressor units have four main (primary) sources of noise: gas-turbine engine; compressor; centrifugal supercharger; fans.

The main sources of noise are paths of suction and exhaust of gas turbine installations.

Let's examine basic reasons of a low effectiveness of the existing silencers of noise suppression systems: pattern incompatibility of absorption and emission spectrum; existence of acoustic bridges (bypassing the silencer) for a sound distribution; insufficiency of a sound-absorbing surface area; defects of a design (assembly gaps. unreasonably large cross sections); short life of the used sound-absorbing material (foam rubber).

The noise suppression of the gas-compressor unit is carried out by four main methods. Training Methods:

- *dissipative noise suppression in paths of suction and exhaust.* For noise reduction by this methods absorber of resonant type are used of which elementary method is the limited air cavity connected by an opening (throat) to environment.

- *use of jet silencers (resonators).* The principle of operation of these silencers is «locking» of extending modes of sound vibrations and their reflection on the channel back to a noise source.
- *active noise suppression in channels.* The physical mechanism of noise reduction when using active methods consists, as well as in case of use of the usual soundproofing systems, in addition of fluctuations with various phases, at the same time however the secondary (compensating) field is created not in the passive way (for example by reflection), but is radiated by special electro-acoustic converters.
- *combination.* Entering of absorption elements of sound energy in jet silencers improves their parameters since sound reflection effect from jet type devices is weakened, and also levels of sound pressure in forming zones of not extending modes of fluctuations are decreased. Sound-absorbing elements provide dissipative withdrawal (drain) of acoustic energy, transferring it to thermal energy. When a sound dissipation in natural absorbers is small, the absorbing elements are introduced into the jet silencers.

4. Thermal influence. Use gas-turbine engines in the gas-compressor unit drive leads also to thermal impact on environment and emergence of geo-ecological factors. Thermal influence of compressor station on environment is especially actual during the operation in the conditions of permafrost.

5. Energy saving problem. The gas consumption on own needs which first of all on fuel gas for gas-turbine engines of gas-compressor units can constitute up to 5% of transportation amount for 1,000 km of the route. Therefore, in absolute value in case of transportation distance more than 5,000 km the gas consumption on own needs of compressor station will be very considerable. The solution of this problem has several aspects:

- decrease in energy consumption for a gas compression due to use of gas-compressor unit with the efficiency high values of the gas-turbine engine and the centrifugal supercharger;
- decrease in pressure lost during gas transportation in a gas pipeline due to: use of pipes with an internal smooth covering; periodic cleaning of the pipeline internal space; use of high-performance equipment and gas piping of compressor station;
- decrease in the general energy consumption due to application of energy saving technology.

During development of gas transportation technology, the gas energy saving is the same factor, as other important resource-saving factors connected with investments, metal investments and operating costs.

The choice of gas transmission technology first of all depends on a ratio between the cost of pipes and the equipment of compressor station on the one hand and the gas consumed for own needs, on the other hand. The final decision shall be made by means of optimization of the economic indicators characterizing efficiency of the project and the ecological safety of the project [20, 23, 27]

III. RESULT AND DISCUSSION

A. Electric gas-compressor units (EGCU)

Use of the electric gas-compressor units radically ensures an industrial and ecological safety. Their use provides:

- exclusion of natural gas use as a fuel for the drive of the gas-compressor unit;
- exclusion of emissions of natural gas combustion products in the atmosphere;
- exclusion of necessity has a toxic oil treatment device;
- absence of compressor station thermal impact on environment;
- absence of noise and vibration pollution;
- high level of resource-saving for compressor station;
- increased level of compressor station reliability;
- possibility to create unmanned technologies of natural gas transportation.

B. Experience of use of electric gas-compressor units

The world electric companies, such as ABB, MAN, Siemens etc. are leaders in research, development and production of electric gas-compressor stations [8, 9]. Electric gas-compressor stations were widely adopted in Europe, America and the countries of the Asia-Pacific Region [6, 7]. Let's review some examples of use of electric gas-compressor stations in the different countries.

The German gas transmission company Thyssengas, is one of regional operators of main pipelines in Germany [1, 2, 23, 26]. At compressor station Hünxe which is located in the federal land Northern Rhine-Westphalia gas-compressor units of 6.3 MW driven by a gas-turbine were used since 1991. In 2000, these gas-compressor units have been replaced with electric gas-compressor units for ensuring environmental friendliness and energy efficiency.

The ALSTOM company installed on Hünxe compressor station the 6 MW adjustable electric motor drive of an alternating current and rotating speed 12700 RPM, made according to the HOFIM technology – high speed-oil free compression system (Fig. 3 (1)).

Also, due to use of electric gas-compressor unit the compressor station Hünxe has been completely automated, including dimensions of compressor station were reduced and emissions of greenhouse gases and leak of oil from lubricating oil systems were excluded.

Experience of the American gas transmission company Columbia Gas Transmission Corp can serve as other example of use of electric gas-compressor unit of the ALSTOM Company at compressor station Rutledge. Originally, the Rutledge station has been developed for use of gas piston engines. However, the proximity of residential communities, noise and a large number of emissions of greenhouse gases from the working gas-compressor unit was not compatible.

These circumstances have forced the company to modernize Rutledge compressor station and to replace gas-piston engines with electric gas-compressor unit. In this case the ALSTOM Company used electrical gas-compressor unit made according to the MOPICO technology – motor pipeline compressor (Fig. 3 (2)).

This unit represents the hermetic compressor driven by an asynchronous engine. The electric motor which is installed in the unit rotates two centrifugal superchargers. Power of these unites is 3 MW, rotating speed is 10,000 RPM.

C. Technologies of electric gas-compressor units

The HOFIM and MOPICO technologies are the main in the world according to which the leading electric companies produce electric gas-compressor units [12, 13].

(1)

(2)

Fig. 3. Electric gas-compressor units made according to the technologies HOFIM and MOPICO

The main features of these units are the arrangement of the high-speed electric motor and compressors in the tight single case, and they are installed on common shaft which is supported by magnetic bearings. Thus, the drive and operating device are connected without gears and couplings (Table 2).

Table 2. Comparison of the MOPIKO and HOFIM technologies [10, 11]

Parameter	MOPIKO	HOFIM
Compression type	Compact	Oil-free
Motor power range	From 3 MW (4,000 HP) to 18 MW (24,000HP)	From MW (4,000 HP) to 18 MW (24,000HP)
Discharge pressure (max)	150 bar	303 bar
Cooling	Process gas, bled after the first compression stage and subsequently recycled into the suction system	High-pressure hydrocarbon gases
Impact on	Emission-free,	Emission-free,

environment	environmentally neutral system	environmentally friendly system
Service requirements	Minimum service and maintenance requirements	Minimum service and maintenance requirements (fewer moving parts)
Dimensions	Small footprint and low weight	Small footprint and low weight
Remote control	Ideally suitable for remote control and unmanned operation	Ideally suitable for remote control and unmanned operation
Operating range	Extended operating range due to enhanced rotor dynamic behaviour	Extended operating range due to enhanced rotor dynamic behavior and the possibility for parallel/series operations

IV. CONCLUSION

Complexes driven by motors for natural gas transportation undoubtedly, in the future will be used most widely in compressor stations. It is defined by the fact that electric gas-compressor units have for this purpose the most powerful objective arguments and extensive possibilities. Thus, in order that an electric motor was used as the main type of mover for the centrifugal supercharger it is necessary to realize the whole complex of actions which will provide uninterrupted power supply for compressor stations.

Underwater electric gas-compressor units of special designs are non-competitive technical means for a natural gas compression on a seabed at development of offshore fields. In this case the highest requirements should be imposed to the electric drive and whole unit concerning reliability of its functioning and providing a continuity of all technological processes of natural gas transportation.

The type of the gas-compressor unit drive shall be chosen based on the system and detailed analysis of technical and economical and other factors in case of construction and reconstruction new and old compressor stations respectively. The reliable and regular natural gas supply of consumers and ensuring development of economy of Europe shall be a main goal of construction and reconstruction of compressor stations.

ACKNOWLEDGMENT

The research was carried out with the financial support of the Russian Foundation for Basic Research (RFBR), the project "Evolution of methodology of technological forecasting of development of the interconnected industrial and social and economic systems at hydrocarbon resources development in the Arctic" No. 18-010-00734.

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