Ecological and economic justification of the utilization of associated petroleum gas at small oil fields of Russia

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Abstract. One of the main environmental problems in oil production in the world today is the utilization of associated petroleum gas (APG) by combustion it in flares. At the same time, this process has enormous economic damage, since APG is a potential raw material that can be used to produce marketable products, power or heat energy. More than 30 billion cubic meters of APG are combusted in flares annually only in Russia, which is about 20% of the total amount of combusted APG in the world. It should be noted that combustion of 1 billion cubic meters of APG is equivalent to the loss of marketable products worth more than 300 million dollars. In the present article, the authors carried out a selection of the optimal method for utilization of APG at small fields in Russia and its environmental and economic justification. The method of power generation directly at the field using gas turbine power station was adopted as the most cost-effective method. The implementation of such a project at the field reduces emissions of pollutants hundreds of times, and payback period does not exceed 2.5 years.

1. Introduction

The oil and gas industry is a dynamically developing sector of the world economy, but produced oil and natural gas is one of the main energy resources on our planet.

The oil and gas industry is one of the main industries ensuring budget formation in the Russian Federation. More than 500 million tons of oil and about 600 billion cubic meters of natural gas were produced in Russia in 2017, as the same time about 50% of crude oil and about 40% of natural gas were exported.

With such significant production volumes and not the largest oil reserves, the resource supply of Russia with oil, according to various estimates, ranges from 20 to 25 years with current production volumes. The situation with natural gas is a little better, as resource supply of Russia with natural gas, according to various estimates, ranges from 80 to 100 years [1].

However, one of the most pressing environmental problems of the oil and gas industrial complex in Russia is the utilization of associated petroleum gas (hereinafter referred to as APG). APG is one of the by-products of the process of oil production and its preliminary preparation for transportation. The main components of PNG are methane and other low molecular weight (volatile) alkanes [2].

Due to a number of technical and economic reasons, as well as due to the peculiarities of the legal regulation of the oil industry, the main method of utilization of APG in Russia and in some other countries today is it combustion in flares [3]. More than 30 billion cubic meters of APG are combusted in flares annually only in Russia, which is about 20% of the total amount of combusted APG in the
As a result, more than 17,000 flares are burning at oil fields and refineries around the world, annually emitting about 350 million tons of CO2, hundreds of thousands of tons of nitrous oxide, carbon monoxide, sulfur dioxide and products of incomplete combustion of hydrocarbons. Emissions of flares are more than 35% by volume all emissions to the atmosphere from the oil and gas industry. In addition, the combustion of APG in the subarctic regions leads to the formation of a large amount of soot deposited on the snow cover, which increases the absorption of solar energy and accelerates the melting of the Arctic ice [4,5].

Figure 1 shows a cartographic model of dispersion in the surface atmosphere of carbon monoxide, emitted by a flare at one of the small deposits of Siberia. Carbon monoxide is one of the major pollutants during the process of combustion of APG and has a toxic effect on living organisms [6]. The coefficients, calculated as the ratio of the current concentration of carbon monoxide to the normative indicator of its concentration in atmospheric air, are marked on contour lines. Thus, this ratio shows how many times the concentration is exceeded relative to the standard.

![Figure 1. Cartographic model of carbon monoxide dispersion in the surface atmosphere](image)

It can be seen in Figure 1 that within a radius of more than 10 kilometers the established standard for carbon monoxide is exceeded dozens of time. At the same time, several other flares of nearby fields fall within the radius of impact of the flare under consideration, the negative impact of which was not taken into account when creating the cartographic model. Consequently, the real environmental situation in the territory under consideration is several times worse.

However, the colossal negative impact on the natural environment is not the only reason for the observed trend to decreasing of the volume of APG combustion in flares and to the search for alternative ways to utilize APG with a positive economic effect. According to the calculations of the Institute of Energy Strategy of Russia, combustion of 1 billion cubic meters of APG is equivalent to the loss of marketable products worth more than 300 million dollars. This fact determines the relevance of the search and implementation of APG utilization methods with an economic benefit for oil producing enterprises and optimization of the ecological situation in regions with developed oil producing industry [7].

2. Materials and methods

There are several generally accepted methods of APG utilization today. The main of which are:
- processing of APG at gas processing plants (deep processing and shallow processing) with a production of marketable products;
- power generation;
- burning for own needs (as a rule, with receiving heat energy);
- injection back into the reservoir for enhanced oil recovery (reservoir pressure maintenance system);
- injection into production wells - using of “gas lift”.

Analysis of publications and fund documents of oil producing enterprises allowed setting that the most effective from the point of view of environmental and economic justification is the processing of APG at the gas processing plant with a production of marketable products [8].

Table 1 presents a comparison of existing methods of utilization of APG based on the required capital costs and economic effect.

Table 1. Comparison of existing methods of utilization of APG

|                  | Combustion | Injection back into the reservoir | Power generation | Shallow processing | Deep processing |
|------------------|------------|-----------------------------------|------------------|-------------------|-----------------|
| Capital costs, USD per cubic meter APG | 0.01 | 0.07 | 0.08 | 0.23 | 0.29 |
| Economic effect, USD per cubic meter APG | 0 | 0 | 0.07 | 0.17 | 0.31 |

From Table 1 it can be seen that the processing of APG at the gas processing plant with the production of marketable products (deep and shallow processing of APG) has an insignificant capital costs compared with the resulting final income. In addition, recycling APG on gas processing plant has a minimal negative impact on the components of the environment in comparison with other methods of utilization of APG [9,10]. However, Table 1 presents the ideal conditions under which gas-processing plant is provided with APG in an amount sufficient to operate it at design capacity and without outages. In addition, only the cost of the product was taken into account when calculating the economic effect, but transport costs, availability of sales markets and other secondary factors were not taken into account [11].

Unfortunately, such conditions on the territory of Russia are found only in very large oil fields with a high flow rate of APG (more than 1 billion cubic meters per year). There are no more than 10 such oil fields on the territory of Russia. Thus, this method is justified technically and economically only if these conditions are met [1].

The bulk of oil on the territory of Russia is produced in medium and small fields, which can be geographically located at a considerable distance from each other and from settlements, which makes it impractical to transport APG. In addition, such fields have a small production rate of APG (not more than 300 million cubic meters per year) and cannot ensure the permanency work of gas processing plant at the designed capacity [12].

The calculations made by the authors showed that for small fields with relatively small oil reserves and, accordingly, small volumes of extracted APG (up to 300 million cubic meters per year), this method is disadvantageous from an economic point of view, since it requires significant capital costs for transportation and storage APG, and also does not ensure the permanency work of gas processing plant at the designed capacity, which reduces the final profit. Thus, the payback period of technical event increases to several decades [13].

Thus, after analyzing fund materials of several dozens of small oil fields in Russia, their prospected reserves and transport accessibility, it was determined that the power generation is universal (in terms of field capacity of APG, taking into account the development of infrastructure, etc.) on the basis of generators with gas turbines [14]. Such installation can even operate on low-quality fuel, which is APG, thereby significantly reducing the operating costs of preliminary preparation of APG for combustion [15]. The generated power energy is used mainly for own needs. At the same time, exhaust gases can be used as a thermal agent in the central heating system of industrial facilities of the
field, or it can be subjected to catalytic purification and released into the atmosphere with concentrations for the main pollutants not exceeding the established standards [16].

The evaluation of prospected reserves of oil, flow rate of oil and APG, as well as the chemical composition of produced oil and APG was carried out based on fund materials.

The calorific properties of APG and the possibility of its use for power generation were carried out by calculation based on the composition of APG.

All calculations were carried out in accordance with the methods certified in Russia.

3. Results

Being one of global largest suppliers of oil and gas, electricity tariffs in Russia are quite low and amount to about 0.05 USD per 1 kW. Nevertheless, the main advantage from an economic point of view is not saving on power energy charges, but the complete elimination of the costs of external power energy supply infrastructure, which, due to the considerable remoteness of deposits, requires considerable capital costs [17].

After analyzing the most popular methods of power generation, it was decided that the best in terms of ecological and economic justification would be to obtain power energy using a gas turbine installation (hereinafter referred to as GTI) [7].

Based on the fund data of gas producing enterprises in Russia, it was found that the average power consumption of small oil field is about 50 MW for every 45 days (period of 1 shift team). The calculations were carried out on the basis for an oil field production rate of APG about 100 million cubic meters per year, and also on the condition that all the produced power energy will be used on the needs of the oil field. Thus economic justification takes into account only the cost of electricity, which the manufacturing entities of field will no consume when the own source of power energy generation appears on the oil field [3,18].

The Russian market has a large selection of GTPP, both domestic and foreign production. Based on the energy intensity of the field, production rate and composition of associated gas, as well as the remoteness of the field from developed infrastructure networks, the choice of power plant was given to the domestic mobile GTPP with an output of power energy 500 MW per year [10].

A safety factor of 20% was also adopted when choosing a GTPP. It is necessary for the prospect of a potential increase in oil production, as well as for additional capacities of power energy during emergencies.

The hourly consumption of APG at full load of the GTPP 12 400 cubic meters, and the annual consumption is 109 million cubic meters. This power plant will fully meet the need of the field in power energy and partially in thermal energy. APG produced in the field is sufficient for the operation of GTPP with work loading about 92% of the design capacity, which is enough for normal operation of the field. If necessary, diesel fuel can be used as a backup fuel.

Exhaust gases from the GTPP enter the waste gas cleaning system, which efficiency reaches 95%. A cartographic model of carbon monoxide dispersion in the surface atmosphere after the project realization was created based on the actual emissions value obtained according to the calculation (Figure 2). The coefficients, calculated as the ratio of the current concentration of carbon monoxide to the normative indicator of its concentration in atmospheric air, are marked on contour lines. Thus, this ratio shows how many times the concentration is exceeded relative to the standard.

It can be seen in Figure 2 that the concentration of carbon monoxide slightly exceeds the established standard for carbon monoxide only within a radius of 1 km, which corresponds to the radius of the sanitary protection zone.

When implementing this project, the flare will completely decommissioned, which allows achieving such a significant reduction in emissions of pollutants into the atmosphere. However, the flare must remain in working condition in case of an emergency shutdown of a GTPP or a short-term increase in the APG flow rate at the field [19].

The cost of operations for the utilization of associated petroleum gas at a gas turbine power plant is determined, on the one hand, by capital costs and, on the other hand, by operating costs. Capital costs
include the cost of the equipment itself and the cost of its delivery and installation costs (construction and installation works), while operating costs include wages and depreciation.

Figure 2. Cartographic model of carbon monoxide dispersion in the surface atmosphere after the project realization

The recoupment of the proposed project will consist of saving on power energy and from the reduction of environmental pays for atmospheric air pollution from APG combustion products in flare [1].

The calculation results of the economic efficiency of the proposed project are presented in Table 2.

|                         |                 |
|-------------------------|-----------------|
| **Capital costs, USD**  | **480 000**     |
| **Operating costs, USD per year** | **52 000** |
| **Reduction of environmental pays for atmospheric air pollution, USD per year** | **230 000** |
| **Saving on power energy, USD per year** | **15 500** |

Thus, based on the calculated data given in the Table 2, it can be concluded that the payback period of the proposed project at a small oil field will be about 2.5 years. At the same time, these calculations did not take into account the savings in the absence of the need to build an external power supply infrastructure, since all the considered fields are operating and the infrastructure on them has already been formed. At the same time, if this project is introduced at the field, where the operation is just beginning, then the absence of the need to build an external power supply infrastructure will save from 200 000 USD, which reduces the payback period by half [14].

4. Conclusion
The authors had conducted a search for the best way to utilize APG in small oil fields in Russia (flow rate of APG up to 300 million cubic meters per year) and had done its ecological and economic justification as part of the work. It can be drawn the following conclusions because of the study:

1. The most economically and environmentally justified method of utilization of APG is processing APG with the production of marketable products (Table 1), but due to many factors, such as poor infrastructure, nature and climate conditions, low volumes of produced APG, this
method is economically justified only for large oil fields (debit APG more than 1 billion cubic meters per year), which in Russia is not more than 10.

2. The most economically justified method of utilization of APG in small oil fields is power generation, while the produced power energy will be used on the needs of the oil field, without obtaining additional income from the sale of electricity. From the point of view of technical equipment, it is optimal to use GTTP as a power generation unit, since GTI are the most unpretentious to the quality of APG, have a block-modular (mobile) design, and are widely represented on the market.

3. Environmental calculations showed that when implementing the proposed method of utilization of oil and gas production, emissions at the field are reduced from thousands of tons per year to several tens of tons per year, which significantly improves the state of the environment and reduces the negative impact on living organisms near the field (Figure 2).

4. The economic justification for the project showed that with a capital expenditure of just under half a million USD and operating costs of about 50 000 USD per year, the payback period for this project will be about 2.5 years for the field being exploited (Table 2). The main economic indicators are savings on environmental pays for air pollution (230 000 USD per year) and savings on electricity (about 15 000 USD per year).

5. At the same time, if we consider the introduction of this method to the newly created field, then the absence of the need to build an external power supply infrastructure will save from 200 000 USD. In this case, the payback period of the project may be a little more than 1 year.

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