Associated Petroleum Gas Utilization: New Opportunities for the Oil and Gas Complex in a Circular Economy

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Abstract. The topic of the beneficial use of associated petroleum gas (APG) remains relevant due to the limited resources and environmental problems. This is the engine for the active development of management theory and practice with a focus on such concepts as resource saving, energy efficiency and circular economy, which determine the vector of environmentally oriented development of industrial enterprises. In this paper, the existing methods of APG utilization are considered, a qualitative comparison of technologies in terms of such parameters as CAPEX, marketable output, prospects for the sale of commercial products, loss of profits, environmental damage, extraction of petrochemical raw materials from APG, technology implementation period is carried out. Based on the example of the Messoyakha fields, the economic efficiency of APG utilization technologies, which correspond to the characteristics of the field (injection into the reservoir, shallow and deep processing) was calculated. The calculations showed that deep conversion is the most effective method of utilization of APG stored in underground gas storage (UGS) of the Messoyakha fields. This method of APG utilization is integrated into the circular economy system and meets its principles.

1 Introduction

Currently, there is a significant growth of interest in the circular economy in industry, including oil and gas [1]. This trend is due to the fact that natural resources are limited. In addition, the problem of environmental pollution is quite acute.

APG flaring annually accounts for more than 35% of all emissions into the atmosphere of the oil and gas industry as a whole [2]. emissions contain hundreds of thousands of tons of NO (nitrogen oxide), CO (carbon monoxide), about 350 million tons of CO_2 (carbon dioxide), sulfur dioxide and other products of incomplete combustion of hydrocarbons. Another important environmental problem is the melting of Arctic ice due to the burning of APG, which leads to the deposition of a large amount of soot on the snow cover, which increases the absorption of solar energy by Arctic ice [3, 4].

At the same time, APG flaring causes enormous economic damage, since APG is a potential raw material that can be processed to produce marketable products, electricity, or used to maintain reservoir pressure in order to increase oil recovery. In Russia, more than 20 billion m^3 APG are flared annually [2].

The limited resources and environmental problems of industry, including in the oil and gas complex, determine active development of the theory and practice with a focus on such concepts as resource conservation, energy efficiency and circular economy [5]. These approaches determine the vector of environmentally-oriented development of industrial enterprises. The APG utilization methods studied in this paper are an example of circular production chains that correspond to such a vector and ensure minimal impact on the environment.

2 Literature review

Based on the literature review, we can conclude that the number of scientific studies on the topic of circular economy (or closed-loop economy) has increased significantly in recent years. Thus, for the query "circular economy" (keywords), SienceDirect displays 17,148 results for the period since 2018. This topic is explored by Jonas Grafström, Siri Aasma (2021), Roberta De Angelis (2021), Ricardo Weigend (2020) and many others.

Circular economy is also associated with sustainable development of organizations. Murillo Vetroni Barros (2021) discusses this topic in his research.

A significant number of scientific publications are devoted to the topic of the closed cycle of water consumption. For example, C. E. Nika (2020), Massimiliano Sgroi (2018), Nikolaos Voulvoulis (2018).

Circular water consumption also refers to the organization of production processes in oil and gas fields. Most large oil and gas complexes now pay sufficient attention to water purification and reuse (for instance, Gazprom Neft [6], Rosneft [7], Lukoil [8]).

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Quite a lot of scientific research is devoted to the topic of APG utilization. Both domestic [9,10] and foreign [11,13] scientists write about the dangers of APG flaring. For example, [2] consider the effectiveness of APG utilization methods in small oil fields; [13] investigate how the role of CO_2 is changing in the transition to a circular economy.

Also, quantitative data and innovative technologies for APG utilization are highlighted in the annual reports of oil and gas companies (for example, [14,15]), Annual Statistical Compilations of the Fuel and Energy Complex [4], research by SIBUR Holding [16].

the literature review revealed that some scientists associate the circular economy and APG utilization in scientific studies [17,18], but, nevertheless, the topic remains understudied. In this regard, the authors made an attempt to investigate methods of APG utilization in the context of circular economy and to present a practical case of the choice of APG utilization method at the Messoyakha fields. The Messoyakha fields are owned by Rosneft and Gazprom Neft (the project operator) and are located in the Tazovsky district.

3 Circular economy in the oil and gas complex

The circular economy is based on the 3R – Reduce, Reuse, and Recycle - principle [19].

In modern economics, the circular economy is understood as a model in which used materials are recycled or released into the biosphere without harmful effects. The tendency to perceive waste not as garbage but as a useful resource is a key feature of the circular economy. The relevance of this approach is also due to the fact that there is a threat of exhaustion of many natural resources.

The introduction of circular economy into production entails changes in economic, environmental and social aspects [20].

Examples of circular production chains in oil and gas production can be water consumption, waste use and beneficial use of APG.

The closed cycle of water consumption eliminates the discharge of contaminated water. construction of large water treatment complexes may allow taking wastewater from various sources for its further use in industrial steam generation, necessary for production of high-viscosity oil [21].

Another option for implementing a circular economy in oil and gas production is the use or sale of company waste. One part of the company's waste is recycled for safety and environmental reasons (e.g., used batteries, fluorescent lamps). Another part (waste of polyethylene, polypropylene, spent catalysts) can be sold as secondary raw materials.

Another option for introducing the circular economy into production is the use of APG. Previously, APG was flared as a by-product of oil production, but there are ways to use APG to reduce emissions and increase the economic efficiency of oil and gas projects (through the sale of the obtained marketable products).

4 Comparative analysis of associated petroleum gas utilization methods

4.1 APG in Russia: measures to reduce the level of APG flaring and statistics

In 2009, a decree "On measures to stimulate the reduction of atmospheric air pollution by products of associated petroleum gas combustion at flare installations" was signed in Russia [23, 24].

This decree establishes the rate of APG flaring at no more than 5% of the total APG production for 2012 and subsequent years. Also, this decree regulates the increase in payments for over-limit APG flaring (an additional factor of 4.5 is introduced) [25].

Figure 1 shows statistics of APG production, APG flaring volumes in Russia, and the APG utilization rate for the period 2000-2019.

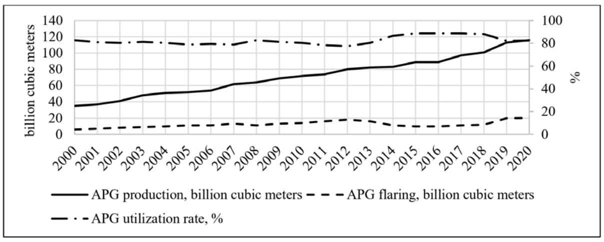

Fig. 1 APG production and flaring in Russia for 2000-2020, billion m^3. The level of APG utilization in Russia in 2000-2020, %. Compiled by the authors on the basis of [4]

During the analyzed period from 2000 to 2020, APG production in Russia is increasing, which is associated with the growth of oil production. From 2012 to 2015, the national average APG utilization rate increased by 13%. The change in this indicator is primarily due to the entry into force of the decree "On measures to stimulate reduction of atmospheric air pollution by combustion products of associated petroleum gas in flares ".

In 2019, the APG utilization rate in Russia was 82.9%, which is 5% lower than in 2018. Thus, the level of APG utilization in Russia had been declining for 2 years. This may be due to the growth of oil production at new fields, which are characterized by an insufficient level of development of the infrastructure necessary for APG utilization.

At the same time, at some large oil and gas fields in Russia the utilization rate reaches 99.6% (Surgetneftegaz) [14]; 97.6% (LUKOIL) [26]; 95.6% (Tatneft) [27].

4.2 APG utilization methods

In world practice today, the main methods of APG utilization are the following [2]: re-injection of APG into the reservoir, injection into the Unified Gas Supply System (UGSS), power generation, simple and deep conversion.

Figure 2 shows APG utilization methods, their description, reflecting environmental and economic aspects of technologies.

Thus, the main methods of APG utilization in the world practice and measures to reduce the level of APG utilization are identified.

APG utilization methods	Description	Economic aspect	Environmental aspect
Re-injection into oil reservoir	This process involves the injection of APG into the gas cap. The goal is to increase oil recovery by increasing the intra-reservoir pressure.	No large capital investments are required. The economic effect depends on the growth of oil recovery in the field.	Environmental impact is considered to be zero.
Injection into the UGSS	Sending part of the APG to the main gas pipeline for sale to consumers. The implementation of such a process is associated with technological limitations (for instance, the distance from the gas pipeline; a certain ratio of APG and natural gas).	Monetizing APG as a conventional fuel gas.	Environmental impact is considered to be zero.
Power generation	APG is sent to gas turbine plants. It can be used in the heat supply systems of the field facilities. When a significant amount of APG is released at the field, the organization of power plants with the delivery of electricity to the regional power supply networks is considered effective.	Sale of electricity or its use for the field's own needs	Gas turbine emissions: NO_2, NO, CO, etc.
Chemical processing (for example, Cyclar and APG in BTK processes)	The Cyclar process is the production of a mixture of aromatic hydrocarbons from the propane-pentane fraction of APG. APG in BTK process: APG is processed into a mixture of aromatic hydrocarbons (for instance, it can be mixed with the main oil stream).	Aromatic hydrocarbon concentrate is a valuable raw material for the petrochemical industry; its independent implementation is possible.	Greenhouse gas emissions CH_4, CO_2 from gas processing plants and petrochemical plants
GTL technology	Technology is based on the Fischer-Tropsch synthesis and the conversion of hydrocarbons into synthesis gas. Syngas is a mixture of carbon dioxide and hydrogen.	Converting gas to liquid to produce liquid hydrocarbons such as naphtha, kerosene, diesel, jet fuel, gasoline, etc.	
Fractional (non-chemical) processing	As a result of fractional processing, the following commercial products are obtained at the output: stable condensate, gas gasoline, propane-butane fraction, etc.	Sales of the received commercial products.	

Fig. 2 Environmental and economic aspects of APG utilization methods. Compiled by the authors based on [16, 28-32]

5 The case of the Messoyakha fields

5.1 Characteristics of the Messoyakha fields

Messoyakhaneftegaz is a joint venture between Rosneft and Gazprom Neft (the project operator). The nearest settlement is the village of Tazovsky, located 140 km away from the Messoyakha fields. The distance to the nearest town (Novy Urengoy) is 340 km.

Production at the Vostochno-Messoyakhskoye field started in 2016, the geological structure of the reservoir enables production at a depth of 800-1000 meters [33].

The gas factor (gas content in the products of oil wells) in the Messoyakha fields averages 360-380 m^3/t. Also, APG is similar in composition to natural gas, since the methane content in APG is 94%.

In 2021, the company commissioned several gas cycle infrastructure facilities at once. At the Vostochno-Messoyakhskoye field there is a compressor station with a preliminary gas discharge unit with annual capacity of 1.5 billion m^3 per year. At the Zapadno-Messoyakhskoye field, there is an underground gas storage (UGS), where APG will be injected until a decision is made on its further useful use. A 47-kilometer gas pipeline will connect these two key facilities.

5.2 Choice of APG utilization methods for the Messoyakha group of fields

Since no decision has been made on the utilization of APG from UGSs at the Messoyakha fields, the authors made an attempt to compare the following methods of APG utilization for the group of Messoyakha fields: re-injection of APG into the oil reservoir, simple conversion and deep conversion.

These 3 methods were chosen for the following reasons:

1. Injection into the Gazprom’s UGSS is associated with a number of technological limitations: remoteness from the main gas pipeline (more than 500 km) [35], a certain ratio with natural gas production.

2. Re-injection of APG into the reservoir for enhanced oil recovery is the most widespread method of APG utilization in Russia, therefore it was chosen for comparison.

3. Commercial products obtained after simple and deep APG conversion are considered to be products with high added value.

5.2.1 Simple and deep APG conversion

The process of conversion of APG into gas chemistry products is carried out by separating the gas from water and oil, then it is pre-processed and sent to a gas processing plant (GPP). APG is re-processed and light fractions of gases are extracted from it, such as: hydrocarbons, dry gasoline-free gas, a mixture of methane and propane.

As a result of gas fractionation, gas mixtures are emitted from NGLs, which are subsequently used as fuel or as raw materials for gas chemistry (BGS and LPG). This concludes the simple conversion process (Figure 3).

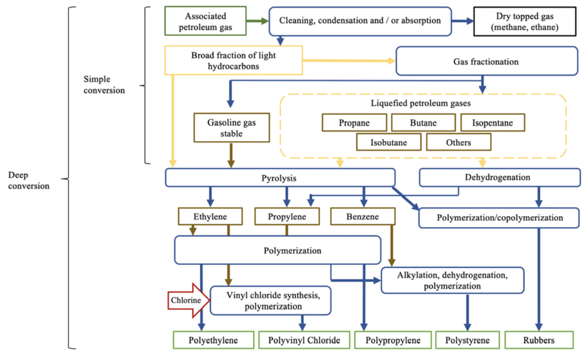

Fig. 3 Associated petroleum gas processing scheme. Compiled by the authors on the basis of [36]

Then, at the GPP, the gas passes through another stage of conversion, which is part of the deep APG conversion. This stage includes pyrolysis, dehydrogenation and polymerization.

5.2.2 Re-injection of APG into the oil reservoir

Due to the pressure difference in the well and in the formation, oil moves to the well. To maintain reservoir pressure, water is injected into the reservoir. But APG can also play the role of the working agent (when injected into the gas cap of the field).

Before re-injection, the APG is separated from the crude oil, it is dried, compressed and is injected into the gas cap in this form (Figure 4).

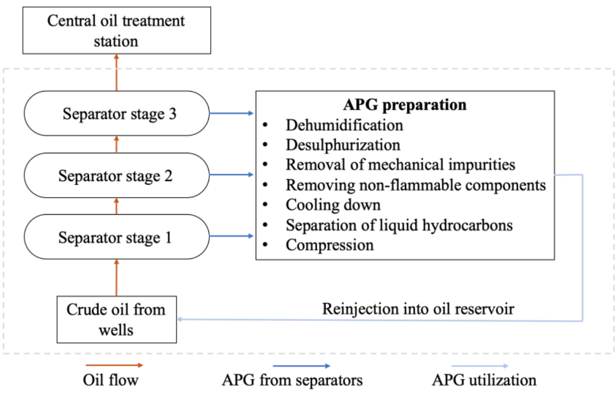

Fig. 4 Technological scheme of APG injection into the reservoir. Compiled by the authors on the basis of [32]

Thus, the characteristics of the Messoyakha fields and possible methods of APG utilization have been identified – APG re-injection into oil reservoir, simple and deep conversion.

5.2.3 Selection of the most effective method of APG utilization for the Messoyakha group of fields

To select the most effective method of APG utilization use at the Messoyakha fields, a qualitative comparative analysis was conducted on such parameters as CAPEX, marketability products, sales prospects, lost profits, environmental damage, extraction of petrochemical raw materials from APG and the technology implementation period (Figure 5). it should be noted that the key parameters are applicability of the technology to the geological conditions of the field, CAPEX, economic benefit, the level of impact on the environment, and the period of implementation of the technology.

Indicators	Re-injection into oil reservoir	Simple conversion	Deep conversion
CAPEX	Construction of a compressor and pipeline facilities	Construction of compressor and pipeline facilities and mini gas fractionating plant	Construction of compressor and pipeline facilities, GPP and gas chemical production.
Market products	Additional volume of hydrocarbon production	Dry gasoline-free gas, LPG and gasoline gas stable	Base polymers (polyethylene and polypropylene), elastomers (polybutadiene), etc.
Sales prospects	Processing at an oil refinery into petroleum products	Sales to petrochemical companies	Automotive industry, construction companies, chemical industry etc.
Lost profits	It is defined as the difference between the values of the economic effects of the most effective method and the calculated one		
Environmental damage	0	Greenhouse gas emissions CO_2, CH_4 from gas processing plants and gas chemical plants	
Extraction of petrochemical raw materials from APG, %	0	Up to 60	Up to 100
Period of technology implementation	Under a year	2-3 years	3-5 years

Fig. 5 Qualitative comparison of APG utilization method. Compiled by the authors on the basis of [16, 32, 37, 38, 39]

Calculations were made based on the following initial data:

1. Discount rate. Since Messoyakhaneftegaz is a joint venture of Gazprom Neft and Rosneft in equal shares, the discount rate is calculated as the weighted average WACC of Gazprom Neft and Rosneft - 10.7%.

2. CAPEX. For reservoir re-injection, CAPEX was calculated by summing the costs of individual units, works and services. When calculating CAPEX for the introduction of simple and deep conversion at the Messoyakha fields, gas processing plants similar in conversion volumes were found, and an amendment was made to the construction of capacities due to the harsh climatic conditions [40].

3. The estimated period is from 2022 to 2043, since according to the project plan, the completion of hydrocarbon production is 2043.

a comparison of disposal methods by quantitative indicators is presented in Table 1.

Table 1. Assessment of the economic efficiency of APG utilization methods. Compiled by the authors.

Indicators	**Re-injection into oil reservoir**	**Simple conversion**	**Deep conversion**
CAPEX, million rub.	458.9	6 000	30 000
NPV, million rub.	88.3	316.7	2920,2
IRR, %	13.9	11.6	12,2
PI	1.19	1.06	1.18
PP, years	14.9	18.9	17.11
Lost profits, million rub.	2 831.9	2 603.5	0

The calculations have shown that for utilization of APG stored in underground gas storages of the Messoyakha deposits, the most effective method is deep processing, which, in its turn, is integrated into the system of the circular economy.

6 Discussion and Conclusion

Thus, methods of APG utilization in the context of circular economy were investigated and the environmental and economic aspects of the main methods were highlighted. The characteristics of the Messoyakha fields were considered, the three most suitable methods of APG utilization were identified, and their economic efficiency was calculated. According to the results of the calculations, the project of deep processing of APG n has the highest NPV indicator (2 920,2 million rubles).

It should be noted that the authors allow an error in the economic calculations performed. This is due to the fact that the initial data were collected from open sources of information, which, in its turn, may be approximate. The authors also considered an ideal situation that takes into account only minimal risks when implementing such technologies at the Messoyakha fields.

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