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ANALYSIS OF ASSOCIATED PETROLEUM GAS UTILIZATION IN RUSSIA AND ABROAD

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Abstract. The article analyzes the current state and prospects of utilization of associated petroleum gas (APG), the main components of which are methane and other low molecular weight alkanes. When separated from crude oil, APG contains hydrocarbons such as ethane, propane, butane, and pentane, as well as water vapor, hydrogen sulfide (H_2S), carbon dioxide (CO2), nitrogen (N2) and other components. Associated petroleum gas containing such impurities cannot be used without purification. The authors noted that the shortage of APG processing capacities both in the Russian Federation and in the world is one of the reasons for the high level of gas flaring in oil fields. In 2022, oil production decreased by 8% (from 82 million barrels per day in 2021 to 76 million barrels per day), while global gas flaring decreased by 5% (from 150 billion cubic meters in 2021 to 142 billion cubic meters). Russia, Iraq, Iran, the United States of America, Algeria, Venezuela, and Nigeria have remained the top seven countries in gas flaring for nine consecutive years since the first of two satellites to monitor gas flares from space was launched in 2012. These seven countries produce 40% of the world's oil annually, but they account for about two-thirds (65%) of the world's gas flaring. Rational methods of utilization of associated petroleum gas were determined, which depend on the conditions of oil production, such as the characteristics of the field, the oil/gas ratio (gas-oil factor), as well as market opportunities for the extracted gas. An algorithm for choosing the technology of rational use of APG in oil and gas companies is proposed. An overview of all APG utilization methods is given, which focuses on unit costs, economic benefits, and the nature of the environmental impact. The innovative experience of the effective use of APG in the USA and Canada is analyzed. Particular attention is paid to the need to solve the problem of the effective use of APG in the world, especially to reduce the volume of flaring.

Keywords: associated petroleum gas, associated petroleum gas utilization, associated petroleum gas flaring, environmental pollution

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ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ ПОПУТНОГО НЕФТЯНОГО ГАЗА В РОССИИ И ЗА РУБЕЖОМ

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Аннотация. Представлен анализ современного состояния и перспектив утилизации попутного нефтяного газа (ПНГ), основными компонентами которого являются метан и другие низкомолекулярные алканы. При отделении от сырой нефти ПНГ содержит такие углеводороды, как этан, пропан, бутан и пентан, а также водяной пар, сероводород (H_2S), диоксид углерода (CO_2), азот (N_2) и другие компоненты. Попутный нефтяной газ, содержащий такие примеси, не может быть использован без очистки. Авторы отметили, что нехватка мощностей по переработке ПНГ как в Российской Федерации, так и в мире является одной из причин высокого уровня сжигания газа на факелах на нефтяных месторождениях. В 2022 году добыча нефти сократилась на 8% (с 82 млн баррелей в сутки в 2021 году до 76 млн баррелей в сутки), в то время как глобальное сжигание газа на факелах сократилось на 5% (со 150 млрд кубометров в 2021 году до 142 млрд кубометров). Россия, Ирак, Иран, Соединённые Штаты Америки, Алжир, Венесуэла и Нигерия остаются семью ведущими странами, сжигающими газ на факелах уже девять лет подряд, с тех пор как в 2012 году был запущен первый из двух спутников для мониторинга из космоса газовых факелов. Эти семь стран ежегодно добывают 40% мировой нефти, но на их долю приходится примерно две трети (65%) мирового объёма сжигаемого на факелах газа. Были определены рациональные методы утилизации попутного нефтяного газа, которые зависят от условий добычи нефти таких как характеристики месторождения, соотношение нефть/газ (газонефтяной фактор), а также рыночные возможности для добываемого газа. Предложен алгоритм выбора технологии рационального использования ПНГ в нефтегазовых компаниях. Даётся обзор всех методов утилизации ПНГ, в котором основное внимание уделяется удельным затратам, экономическим выгодам и характеру воздействия на окружающую среду. Проанализирован инновационный опыт эффективного использования ПНГ в США и Канаде. Особое внимание уделяется необходимости решения проблемы эффективного использования ПНГ в мире, особенно для сокращения объёмов сжигания на факелах.

Ключевые слова: попутный нефтяной газ, утилизация попутного нефтяного газа, сжигание попутного нефтяного газа на факелах, загрязнение окружающей среды

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1. Introduction

The total global oil production in 2021 was approximately 90 million barrels of oil per day (b/d) [1]. The USA Energy Information Administration [2] estimated that 99.4 million b/d of petroleum and liquid fuels was consumed globally in August 2022, up by 1.6 million b/d from August 2021 (**Fig. 1**). As the natural gas prices quadrupled in Europe, tripled in Asia, and doubled in the USA, it is expected that the oil consumption will continue to increase globally in 4Q22 and 1Q23 as electricity providers, particularly in Europe, may switch to oil-based generating fuels.

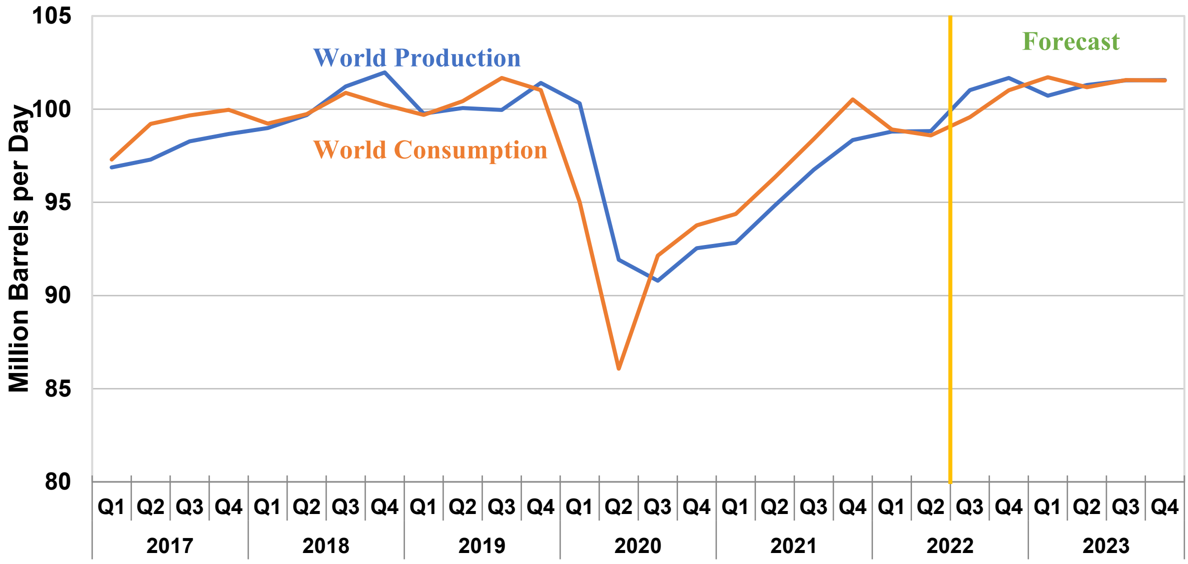

Fig. 1. World Oil Production and Consumption in million barrels per day [2, 3]
Рис. 1. Объёмы добычи и потребления нефти в мире (млн баррелей в сутки) [2, 3]

As stated by Green et al. [4] the production life of a conventional oil reservoir is often split into three stages:

- In primary recovery, crude oil is produced as result of the natural pressure existent in the reservoir.
- In secondary recovery, water or gas is injected into the formation to maintain the reservoir pressure.
- After secondary recovery, approximately 70% of the original oil in place (OOIP) remains in the reservoir; therefore, the operator should consider the application of a tertiary recovery method (also known as EOR). These methods can reverse the production decline of mature reservoirs and increase the overall percentage recovered produced.

The research done by the Asian Development Bank [5] has concluded that the choice of the Enhanced Oil Recovery (EOR) method in each case depends on the reservoir geological characteristics and properties, the degree of depletion, as well as economic considerations. Gas injection methods for EOR, mainly involving CO_2, accounts for approximately 60% of EOR production in the United States of America. Results from the application in the USA show that, depending on the miscibility between crude oil and CO_2, the Carbon Dioxide-Enhanced Oil Recovery (CO_2-EOR) can boost oil recovery by 5% to 15% of the OOIP [5].

In conformity with Perera et al. [6], CO_2-EOR is not a new technology. In the United States, it has been applied since the mid-1980s, in the Permian Basin, West Texas and Eastern New Mexico. There were around 100 CO_2-EOR projects by the year of 2008, which were responsible for additional 250,000 barrels of crude oil per day. Government subsidies and the availability of cheap supplies of CO_2 were appointed as the main reason for its success. However, due to its high impact in the carbon capture, utilization and storage (CCUS), the technology has started to be implemented outside the USA [6].

The International Energy Agency's new global database of enhanced oil recovery projects (**Fig. 2**), shows that around 500 thousand barrels of oil are produced daily using CO_2-EOR today, representing around 20% of total oil production from EOR [7].

In addition to its potential to increment oil production, CO2-EOR is getting intensive scrutiny by industry, government, and environmental organizations for its potential for permanently storing CO_2. Apart from maximizing oil recovery, the CO_2-EOR at the same time is offering a bridge to a reduced carbon emissions future. CO_2-EOR effectively reduces the cost of sequestering CO_2 by earning revenues for the CO_2 suppliers to the oil production companies.

The aim of this paper is to provide a detailed study of the carbon dioxide enhanced oil recovery (CO_2-EOR) process and a comprehensive literature and projects review.

The deterioration of the state of the natural environment leads to a decrease in the quality of life of the population, which is expressed in an increase in the incidence of various types of diseases among the population and in accelerated degradation and destruction of infrastructure facilities.

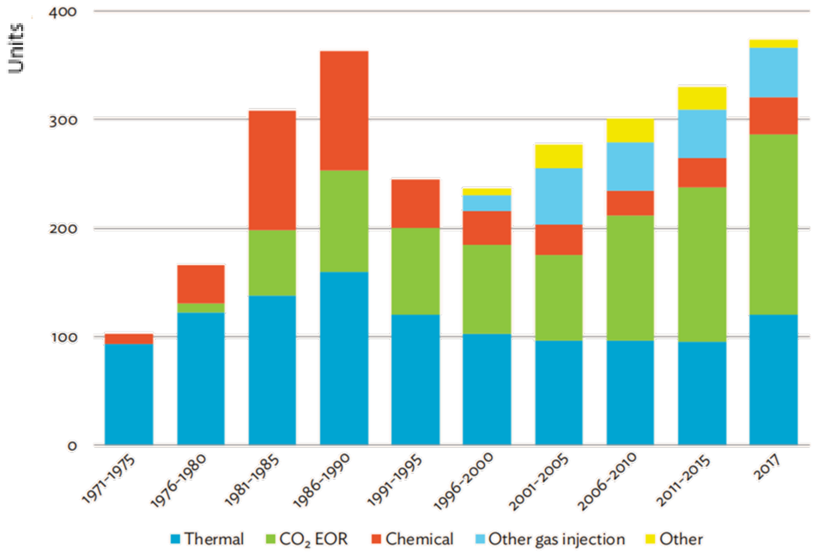

Fig. 2. Number of Enhanced Oil Recovery projects in operation globally, 1971-2017 [7, 8]
Рис. 2. Число проектов третичного метода нефтедобычи в мире в период с 1971 по 2017 годы [7, 8]

2. Global data on of associated petroleum gas flaring

Billions of cubic meters of natural gas are flared annually at oil production facilities around the world. Flaring gas is a waste of a valuable energy resource that can be used to support economic growth and progress.

Since 2012, the World Bank's Global Gas Flaring Reduction (GGFR) Community, in partnership with the USA National Oceanic and Atmospheric Administration (NOAA) and the Colorado School of Mines, has developed global estimates of gas flaring in 2020 based on satellite observations. The satellite's sensors detect the heat given off by gas flares in the form of infrared radiation from global oil and gas facilities. The Colorado School of Mines and GGFR quantify and calibrate these infrared emissions to provide reliable estimates of global gas flaring.

In 2020, global oil production fell by 8% (from 82 million barrels per day in 2019 to 76 million barrels per day in 2020), while global gas flaring fell by 5% (from 150 billion cubic meters in 2019 to 142 billion cubic meters in 2020) [9]. Russia, Iraq, Iran, the USA, Algeria, Venezuela, and Nigeria have remained the top seven gas flaring countries for nine consecutive years since the first of two satellites was launched in 2012 (**Table 1**). These seven countries produce 40% of the world's oil each year, but account for about two-thirds (65%) of the world's gas flaring. Russia tops the list of gas flaring countries in 2020, accounting for 15% of global gas flaring. Across Russia, there are mixed signs: a significant increase in flaring at oil production facilities in Eastern Siberia, along with significant improvements in the reduction of flaring in the Khanty-Mansi Autonomous Okrug region of Western Siberia.

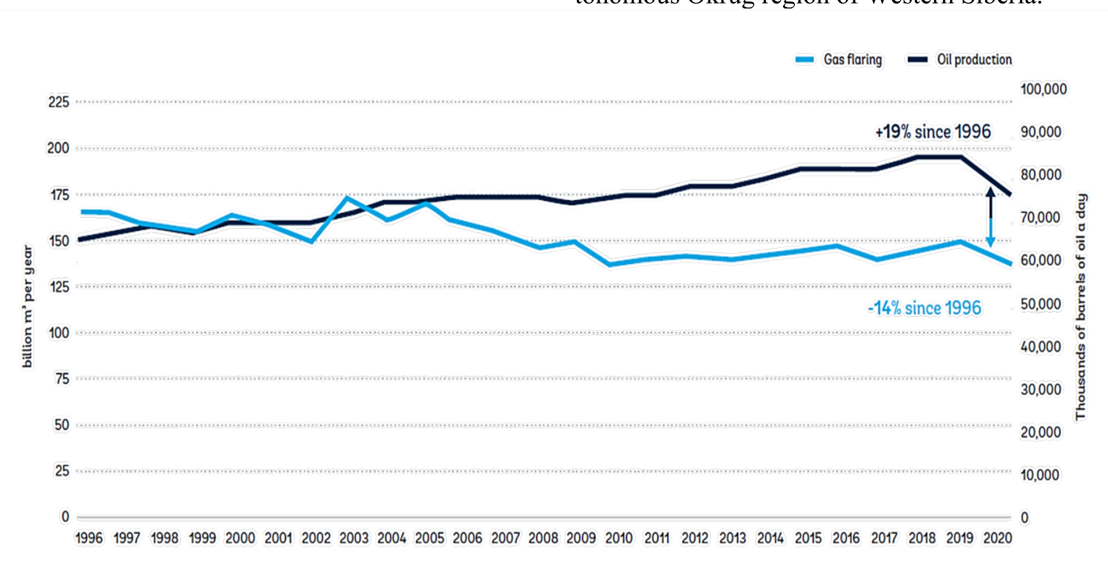

Fig. 3. Global Gas Flaring and Oil Production: 1996 to 2020 [9]
Рис. 3. Объёмы сжигаемого попутного нефтяного газа и добычи нефти в мире в период с 1996 по 2020 годы [9]

Table 1. Ranking of countries by associated petroleum gas flaring in 2016–2020*
Таблица 1. Рейтинг стран по сжиганию попутного нефтяного газа в 2016–2020 гг.*

Country	2016	2017	2018	2019	2020	Change 2020-2019
Russia	22.372	19.916	21.280	23.212	24.88	1.66
Iraq	17.730	17.843	17.821	17.914	17.37	-0.54
Iran	16.405	17.670	17.278	13.781	13.26	-0.52
USA	8.862	9.475	14,069	17.294	11,81	-5.48
Algeria	9.100	8.803	9.009	9.343	9.32	-0.02
Venezuela	9.350	6.997	8.225	9.541	8.59	-0.95
Nigeria	7.315	7.646	7.435	7.825	7.20	-0.63
Mexico	4.776	3.789	3.893	4.484	5.77	1.28
China	1.96	1.56	1.82	2.02	2.72	0.70
Oman	2.816	2.601	2.536	2.631	2.52	-0.11
Libya	2.353	3.908	4.672	5.124	2.47	-2.65

* Compiled by the authors based on GGFR Report (in billion m^3) [1, 9]

The United States accounted for 70% of the global decline, with gas flaring down 32% from 2019 to 2020 due to an 8% drop in oil production coupled with new infrastructure to use gas that would otherwise be flared at torches.

3. In Russia

In Russia, the largest gas flaring country since our data became available increased gas flaring by 8% from 2019 to 24.6 billion cubic meters in 2020 (**Fig. 4**). However, Khanty-Mansi Autonomous Okrug, historically the largest oil and gas flaring region, has steadily expanded its gas utilization infrastructure over the past few years and currently accounts for only 20 percent of Russia's total gas flaring. Flaring in Khanty-Mansiysk Autonomous Okrug decreased from more than 20 billion cubic meters. m in the mid-2000s to less than 5 billion cubic meters. m in 2020 [9].

The situation is different in Eastern Siberia, where oil production from a small number of fields continues to increase. In this remote and vast region, gas flaring increased from 23% (4.8 bcm) of the country's total flaring in 2018 to 33% (8.2 bcm) in 2020. Eastern Siberia would be informally known as the “middle of nowhere”: despite having huge oil reserves, it is an extremely sparsely populated region with little gas infrastructure and very little local demand for gas or gas products. Here, reducing gas flaring will require major investment in new gas infrastructure or conservation by re-injecting the gas back into the ground, if geologically feasible.

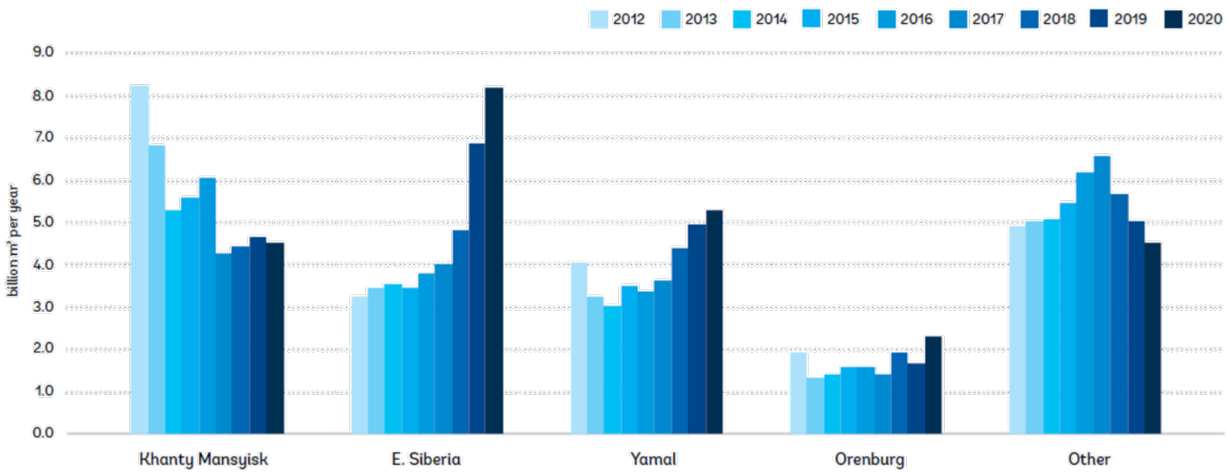

Fig. 4. 2020 Flare volumes, Russian regions [5]
Рис. 4. Объёмы сжигаемого попутного газа нефтяного газа по регионам России в 2020 году

Because during this period the oil production conditions have not changed significantly, it can be assumed that the volume of APG recoverable will change proportionately to the volume of oil produced. But we see, however, different results. In fact, this is the loss of a valuable energy resource that can be used to promote the sustainable development of producing countries. Thus, 142 billion m^3 of associated petroleum gas flared in 2020 can turn into 750 billion kWh of electricity, which exceeds its total annual consumption by all countries of the African continent [10].

4. Rational methods for associated petroleum gas utilization

Currently, there are other possible alternatives to associated petroleum gas flaring, including but not limited to the following:

- Re-injection of APG into the reservoir to maintain reservoir pressure and enhance oil recovery from reservoirs or for its possible conservation as a resource and use in the future.
- Use of APG as an energy source at the production site or at oil production facilities in the immediate vicinity.
- The most efficient way to dispose of associated petroleum gas is to process it at gas processing plants to produce Dry Purified Gas (DSG), NGL, Liquefied Natural Gas (LNG) and Stable Gasoline (SGB).

Below is an overview of the main APG utilization methods, which focus on unit costs, economic benefits, and environmental impacts (see Table 2).

The choice of the optimal option for the use of associated petroleum gas depends on the oil production conditions, such as the geological structure of the field, the gas-oil ratio, as well as the market opportunities for the recovered gas.

Table 2. Comparison of data for all associated petroleum gas utilization methods*
Таблица 2. Сравнение методов утилизации попутного нефтяного газа*

Utilization methods	Capital investments, rub/m^3	Economical effect, rub/ m^3	Lost profit, rub/ m^3	Environmental damage mln tons of CO_2 -equivalent / bln. m^3
Flaring	0.1 (Construction of a flare unit and supply pipelines)	–2.8 (Damage in the amount of a fine for gas flare)	from –2.8 to –22.6 (Range from savings on fines to income from sales of petrochemical products)	7.1 (Emissions of harmful substances into the atmosphere)
Re-injection	4.4 (Collection system and gas injection wells)	0 (Possible increase in oil recovery)	from –3 to –19.8 (Range from savings on fines to income from sales of petrochemical products)	0 (Ecological effect is taken equal to zero)
Deep processing	13.8 (Maximum capital costs for the creation of the entire infrastructure complex: the APG collection system, compressor stations and gas processing facilities, transportation of dry gas and natural gas liquids, costs for further processing)	19.8 – 20.1 (Average economic effect - monetization of methane (dry stripped gas) as a fuel gas, monetization of NGL as a feedstock for petrochemicals with further production of final products from polymers and synthetic rubber)	0 (There is no profit lost (deeper processing within the framework of the model is impossible))	0 (Typical greenhouse gas emissions CO_2, CH_4, N_{ox} from gas processing plants and petrochemical plants (according to RUPEC data), taking into account the greenhouse effect coefficients of each gas)
Electricity generation	54.2 (APG collection system, gas turbine units)	3.6 – 5.2 (Income from own power generation)	from –2.4 to –14.6 (Range from revenues from utilization at mini-gas processing plants to revenues from the sale of petrochemical products)	1.2 (Environmental risks with carbon emissions from large-scale power generation)

* Compiled by the authors based on reporting data from the SIBUR Company [11]

During the years of 2005 and 2015, the volume of APG flared in the Russian Federation has decreased. The increase in the volume of deeply processed APG is covered by a decrease in the volume of shallow processing (**Fig. 5**).

The indicator of rational use of APG has remained stable since the 2000s - within 73-79% of the total amount of APG produced in the country. Only in 2014-2015, according to public reports of companies, it increased to 85-86% [9, 12]. Amendments to the Law “On Environmental Protection” (No. 219-FZ), adopted in July 2014, led to such a noticeable decrease in the volume of associated petroleum gas flaring; under these amendments, the company is obliged to set its technological standards at the highest possible level. The total amount of investment in increasing the rational use of APG was estimated at 200 billion rubles [13].

When supplying APG in small volumes, one of the directions for its utilization is the innovative technology to produce liquefied natural gas NGL Pro. The NGL Pro process integrates dehydration, compression, refrigeration, and conditioning, eliminating the need for costly glycol and refrigeration units. Hydrate formation is eliminated by the thermal integration system (**Fig. 6**). The technology was developed by ASPEN and is used in many areas in the USA and Canada (**Fig. 7**).

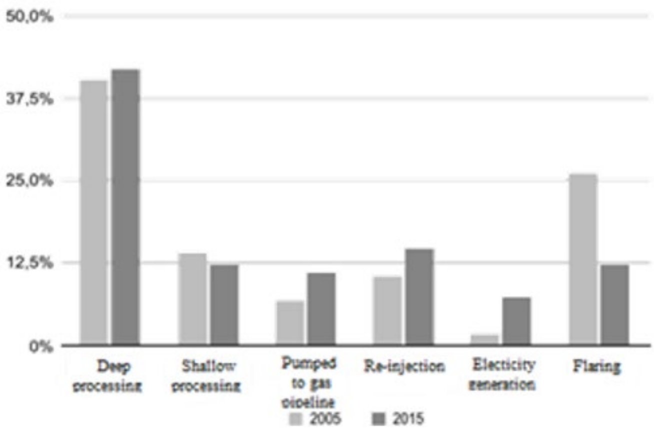

Fig. 5. Comparison of the associated petroleum gas utilization methods in 2005 and 2015 [6]
Рис. 5. Сравнение объёмов утилизации попутного нефтяного газа различными способами в 2005 и 2015 гг. [6]

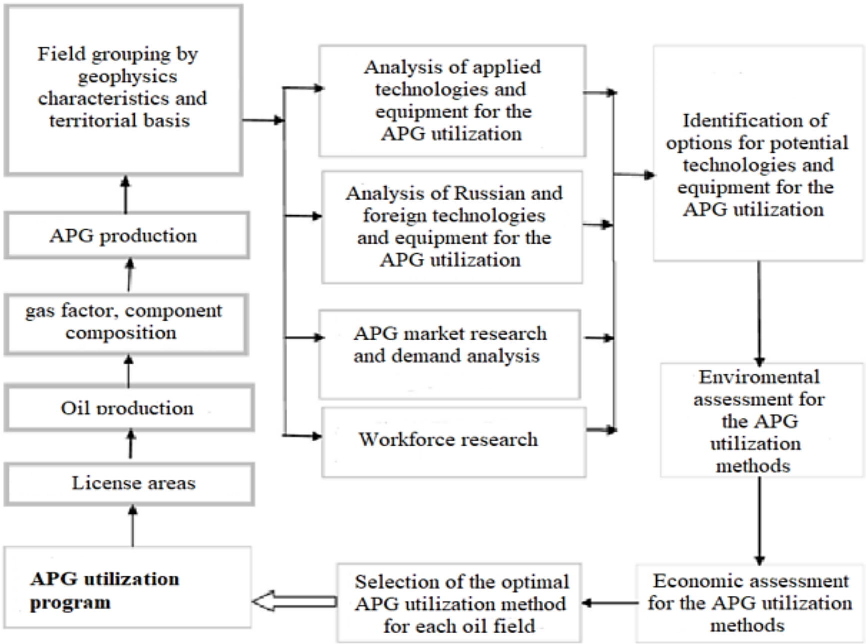

Fig. 6. Algorithm for a rational associated petroleum gas utilization in the oil fields [8, 6]
Рис. 6. Алгоритм рациональной утилизации попутного нефтяного газа на нефтяных месторождениях [8, 6]

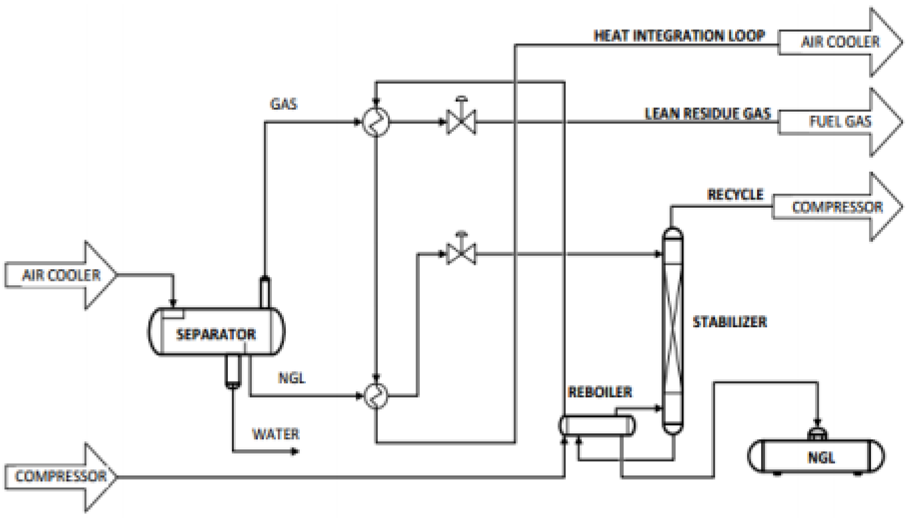

Fig. 7. System of operation of NGL-Pro technology [14]
Рис. 7. Технологическая схема NGL-Pro [14]

Advantages of this technology: a) production of valuable NGL; b) the formation of ice and hydrates is excluded; c) is transferred, mounted on a slippery system; d) Safe and easy maintenance - no moving parts. The method is used at the North Dakota field, the NGL production rate is 379 barrels per day, which leads to a reduction in APG flaring by 42%. The method is used in combination with other methods to increase the level of NGL production and thereby eliminate combustion [14].

5. Conclusion

An analysis of the current state and prospects for APG utilization showed that due to APG flaring, there is a noticeable deterioration in the quality of the natural environment, resulting in: environmental pollution by combustion components; degradation and withdrawal of part of the land from economic circulation, due to thermal effects; reduction in the number of animal and plant species. The analyzes carried out made it possible to prove that, in the medium and long term, APG flaring leads to lost profits and direct economic damage. Any of the alternative (rational) methods of APG utilization allows you to get a positive economic effect - from a simple zeroing of penalties (reinjection of APG back into the oil reservoir) to receiving money from the sale of processed products (electricity and heat, dry gas, fuel, polymers).

Thus, recommendations for the utilization of associated petroleum gas, depending on the volume of its production, are:

- For small volumes – covering own energy needs.
- In case of increase in volumes – power generation and primary processing of APG to obtain SOG as a fuel for a boiler house and NGLs for discharge into an oil reservoir.
- With resources from 50 to 150 million m^3/year - processing to produce dry gas, as well as biogas, liquefied gas, and electricity.
- For APG volumes exceeding 150 mln m^3/year, it is recommended to process into dry gas, NGL, stable natural gasoline (BGS).

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