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# Cryogenic Technologies for Preparation of Hydrocarbon Products and Helium from Associated Petroleum Gases

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**Abstract**—Cryogenic technologies for combined extraction of commercial products, including helium, from associated petroleum gases with minimum energy costs and capital investments were described. The Geliimash Scientific and Production Association, Open Joint-Stock Company, undertakes the manufacture of the whole range of equipment for these technologies.

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In recent years, the interest in utilization of associated petroleum gas (APG) has sharply quickened in the world. From an environmental perspective, associated petroleum gas flaring accounts for ca. 1% of total greenhouse gas (carbon dioxide) emissions worldwide. Huge amounts of pollutants released into the atmosphere as a result of APG flaring include over 250 hazardous chemicals which pose a potential hazard to the natural environment and human health. On the other hand, gas flaring represents a destruction of valuable nonrenewable natural resources.

According to official statistics, at the beginning of the XXI century the major regions responsible for associated gas flaring were the Persian Gulf, West Africa (primarily Nigeria), and Russia (primarily West Siberia). Based on official accounting, until recently, Nigeria had the lead in the amount of flared associated gas (24.1 billion $m^3$ per annum); second to Nigeria was Russia (14.9), followed by Iran (13.3), Iraq (8.6), and Angola (5.4).

The leadership in an effort aimed to solve the associated gas flaring problem was taken by the World Bank which established in 2002 the Global Gas Flaring Reduction (GGFR) partnership. It brings together the major oil-producing countries (US, Canada, Nigeria, Kazakhstan, United Kingdom, Norway, etc.), major energy companies (Exxon, Mobil, Shell, BP, Chevron, ENI, etc.), and international bodies (World Bank, OPEC, and the European Union). Noteworthy, the Russian Federation is represented in the partnership by Khanty-Mansiisk Autonomous District alone.

It is difficult to estimate the amounts APG that is being produced and burned in Russia because of imperfect measurement, inventory, and assessment techniques and facilities for gas resources. The official statistical data do not rely on precise instrumental measurements of the APG volumes produced and utilized; most of oil fields are not equipped with APG meters, and the reports presented by oil companies on its engineering applications do not always reflect the reality. According to the Russian Federation Ministry of Natural Resources and the Environment, 15–17 billion $m^3$ of gas is flared in Russia annually, which figure is comparable with the destruction of 16 million tons of oil (3.5% of the annually produced amount).

Today, utilization of APG is more than ever pressing for Russia, because this will allow accomplishing a serious task of gasification of remote and hardly accessible areas in Russia. The processed APG can be delivered from oil fields to remote areas by road, rail, air, or river transport. Inexpensive and not time consuming (no need in laying pipelines), this option for APG utilization is more advantageous economically than the transportation through gas pipelines.

The Geliimash Scientific and Production Association, Open Joint-Stock Company (OAO NPO Geliimash) offers an APG utilization technology that is

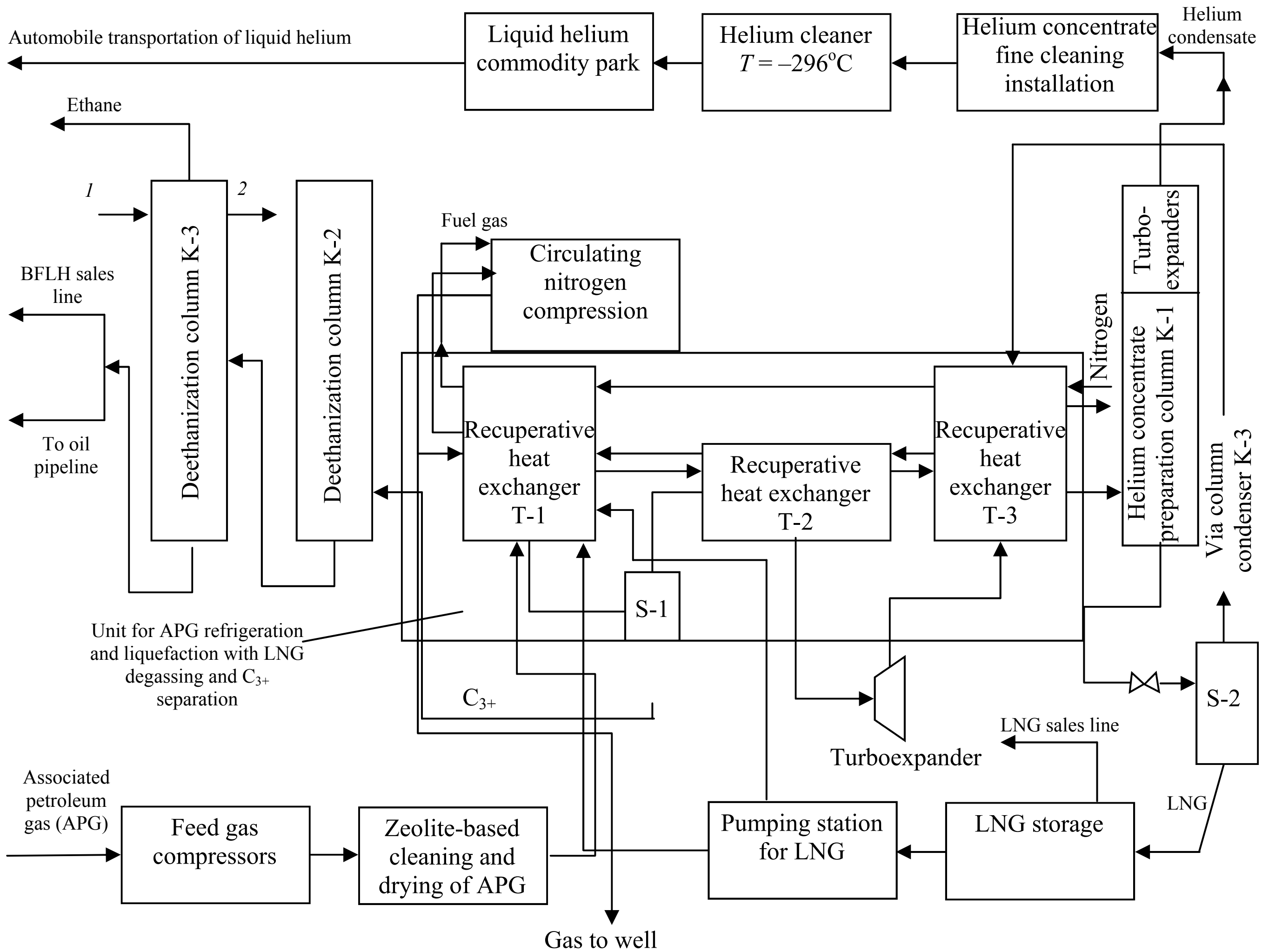


**Fig. 1.** The APG utilization scheme offered by OAO NPO Geliimash.

shown schematically in Fig. 1. The characteristics of the initial APG are listed in Table 1.

In this procedure, the APG from oil field is initially supplied to feed gas compressors for compression to a pressure of 2.5 MPa and further to a cleaning and drying unit consisting of alternately operating zeolite adsorbers. The cleaned gas having a temperature of 20°C is supplied to a refrigeration and liquefaction unit comprised of successive recuperative heat exchangers, where it undergoes liquefaction via a nitrogen refrigeration cycle with degassing of the methane-nitrogen-helium fraction and separation of the $C_{3+}$ fraction (broad fraction of light hydrocarbons, BFLH).

In the first stage, the APG stream is cooled to –80°C in order to achieve the most exhaustive separation of $C_{3+}$ hydrocarbons. The resulting $C_{3+}$ fraction containing a minor amount of dissolved methane and ethane is supplied to the demethanization and deethanization unit for isolation of marketable BFLH to be further delivered to consumers. Ethane can be either used as fuel gas for meeting the power needs of the oil field or sold to outside parties, and methane is returned to the second stage exchanger of the refrigeration and liquefaction unit to be mixed with the methane–nitrogen–helium fraction.

In the third stage exchanger, the stream of the methane-nitrogen-helium fraction is exhaustively liquefied (–120°C), after which it enters the separation unit which consists of a distillation column with liquid nitrogen as reflux. The bottom product of the column is the methane–nitrogen fraction (Table 2) whose composition is similar to that of liquefied natural gas (LNG). The methane-nitrogen fraction is fed to storage wherefrom it can be delivered consumers or, after gasification, be injected into the reservoir. The helium concentrate, taken from the column top, is supplied to the fine cleaning unit for recovering pure helium.

A feature characteristic of the scheme proposed is that the methane-nitrogen fraction is gasified under the pressure generated by liquid pumps. This enables significant saving of the energy costs of compression of the gas to be injected into the reservoir and reducing capital expenditures through the use of cheaper pumps instead of high-pressure compressors.

Table 3 presents the energy costs for the APG utilization process based on the use of a nitrogen refrigeration cycle with turboexpanders and liquid pumps.

The OAO NPO Geliimash undertakes manufacture of a diversified range of gas processing equipment.

**Heat exchangers:**

– of coil-wound type, with statically uniform arrangement of finned tubes;

– of coil-wound flat-tube type, with sparse layered tubes arranged in checkerboard pattern;

– of coil-wound type, with extended heat-exchange surface (Fig. 2); and

– of coil-wound type, with cycloid-wound tubes.

The heat exchangers of the type shown in Fig. 2, designed at the OAO NPO Geliimash for cryogenic plants, proved to be so efficient, both in the design and

**Table 1.** Characteristics of the associated petroleum gas subject to processing

| Characteristics | Value |
|---|---|
| Flow rate $Nm^3\ h^{-1}$ ($kg\ h^{-1}$) | 300000 (288200) |
| Temperature, °C | 20 |
| Pressure, atm | 2.5 |
| Composition, vol %: | |
| methane | 72.78 |
| ethane | 12.66 |
| propane | 4.91 |
| *i*-butane | 0.92 |
| *n*-butane | 1.84 |
| *n*-pentane | 0.91 |
| helium | 0.20 |
| hydrogen | 0.02 |
| nitrogen | 5.76 |

**Table 2.** Characteristics of the methane–nitrogen fraction versus standard LNG

| Characteristic | LNG according to TU (Technical Specifications) 51-03-03-85 | Methane–nitrogen fraction |
|---|---|---|
| Composition, vol %: | | |
| methane | 92±6 | 92.5 |
| ethane | 4±3 | 6.4 |
| $C_{3+}$ | 2.5±2 | 0.4 |
| nitrogen | 1.5±1.5 | 0.7 |
| Net heating value, $MJ\ m^{-3}$ ($kcal\ kg^{-1}$) | 39.1 (11289) | 49.12 (11740) |
| Mass proportion of hydrogen sulfide and mercaptan sulfur, %, max | 0.005 | lacking |

**Table 3.** Energy costs for the proposed APG utilization scheme

| Energy cost type | Amount, MW |
|---|---|
| Nitrogen cycle compressors | 167 |
| Booster compressor (balanced by the brake circuit of turboexpander) | 28 |
| Nitrogen liquefaction | 20 |
| LNG pumps | 2 |
| Total | 189 |
| Specific energy consumption (per cubic meter of the), kW processed gas $m^{-3}$ | 0.63 |

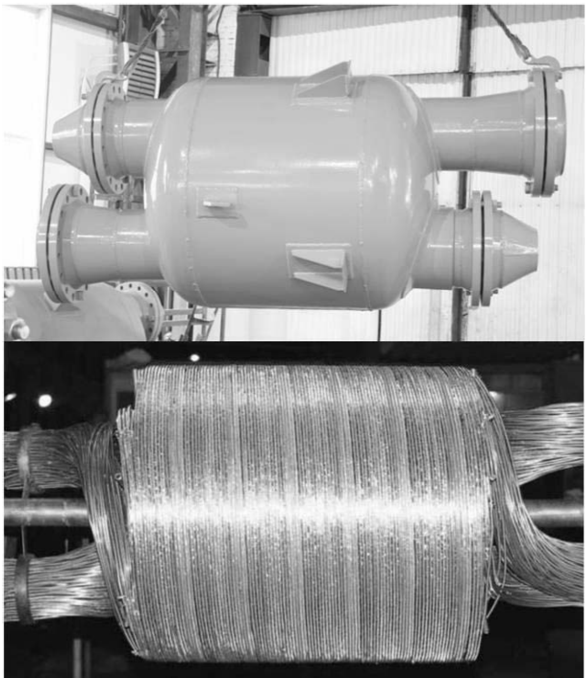

**Fig. 2.** Coiled heat exchanger with high-developed heat-exchange surface.

technology, and versatile that they gradually came into use in virtually all sectors of industry.

All of the above-listed heat exchangers can operate with helium, hydrogen, nitrogen, oxygen, neon, water, natural gas, air, lubricant, and fuel oil as the working liquid; their tubes can be made of stainless steel, copper, brass, and aluminum. The operating temperatures may range from –270 to +900°C, and the operating pressures, from 0.04 to 40 MPa. The process equipment available at OAO NPO Geliimash allows manufacturing heat exchangers with the total mass of up to 40 ton.

**Turboexpanders:** those intended for liquefaction of air and nitrogen; helium; hydrogen; and natural gas. Table 4 lists the parameters of the commercially available turboexpanders.

Figure 3 presents a turboexpander unit with adjustable guide apparatus and magnetic bearings; it is intended for low-temperature separation line of the installation for integrated treatment of natural gas at the gas processing plant in Surgil, Uzbekistan.

**Apparatuses and installations for production of BFLH and LNG and for helium concentration.** The OAO NPO Geliimash has extensive experience in development and implementation of large-scale Russian technologies for production of BFLH and LNG and helium concentration, as confirmed by long-standing cooperation with Gazprom Open Joint Stock Company.

**Apparatuses and installations for helium concentrate cleaning and installations for helium liquefaction.** The OAO NPO Geliimash developed an original cleaning technique for helium concentrate at a medium pressure, which was successfully implemented at the Orenburg helium processing factory at the unit for helium cleaning and liquefaction. Further improvement of this technology implies the combined application of short-cycle and cryogenic methods for isolation of impurities.

The OAO NPO Geliimash undertakes development and manufacture of cryogenic and refrigerating installations for different temperature levels. Over 80 large helium projects have been implemented by OAO NPO Geliimash at various industrial, gas processing, and power engineering entities, as well as in research and academic institutions. In particular, the Europe's biggest center for liquid helium production in Orenburg is equipped with liquefiers of helium, available from OAO NPO Geliimash.

**Table 4.** Range of turboexpanders produced by the OAO NPO Geliimash

| Operating parameter | Turboexpanders for liquefaction of indicated gas | | | |
|---|---|---|---|---|
| | air and nitrogen | helium | hydrogen | for natural gas |
| Gas pressure, MPa: | | | | |
| at the inlet | 0.4–20.0 | 0.4–2.8 | 1.0–12.0 | 1.0–7.0 |
| at the outlet | 0.12–0.5 | 0.03–0.15 | 0.03–7.5 | 0.3–2.0 |
| Gas temperature, K | | | | |
| at the inlet | 110–300 | 8.5–164 | 35–69 | 200–300 |
| at the outlet | 80–130 | 4.2–140 | 21–43 | 172–250 |
| Rotor rpm rate, vol % | 5000–220000 | 125000–250000 | 50000–100000 | 18000–100000 |

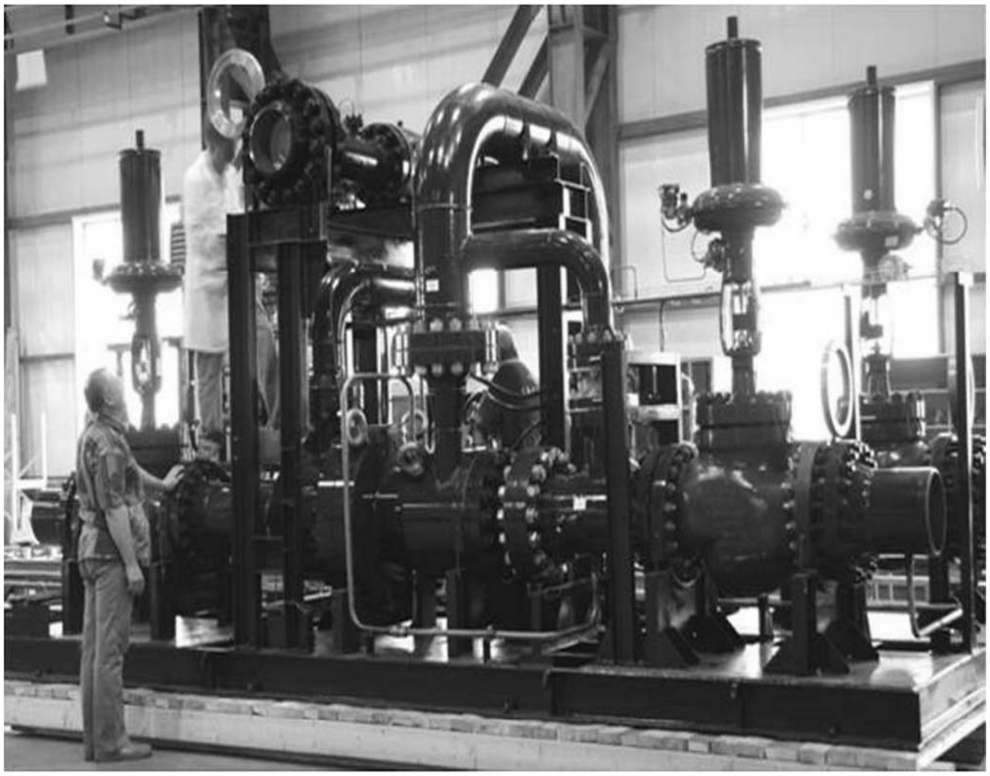

**Fig. 3.** Turboexpander unit with adjustable guide apparatus and magnetic bearings.

**Equipment for liquefied gas storage and transportation.** So far, a 40-$m^3$ prototype cryogenic container for liquid helium transportation has been tested by the OAO NPO Geliimash. Commercial production of such containers is expected to begin in the future, which will allow Russia to undertake independent transportation of liquid helium to external and internal markets.

Thus, OAO NPO Geliimash has the necessary logistical support for creation of facilities for APG processing by the scheme proposed.

Among the commercial advantages offered by the APG utilization options with the use cryogenic technologies, the following deserve mentioning:

(1) The cost of APG treatment products exceeds by an order of magnitude that of the feedstock, which allows implementation of a commercially viable project.

(2) The resulting hydrocarbon products can be transported by any carrier.

From an environmental perspective, the APG utilization by cryogenic technologies will eliminate emissions into the atmosphere of both APG and its burning or processing products and allow development of technologies for complete APG utilization.

Based on the scheme proposed for cryogenic processing of APG it will be possible to:

– isolate valuable components: BFLH, ethane, and strategically important and expensive helium from natural gas and avoid their loss during oil extraction and in-field processing;

– organize a cycling process whose energy costs are minimized via rejecting expensive and low-efficient high-pressure compressors ($P$ = 26 MPa) having a limited service life;

– minimize the mass-dimension characteristics of the equipment operating at the processing plants and reduce the capital costs and costs of delivery of the equipment to hard-to-reach oil extraction areas;

– obtain an additional fuel and energy product, LNG, to be used for meeting the local needs of transport, energy, and communal sector; and

– gain a multiplicative effect from introduction of the cryogenic technology and reduce the specific oil extraction costs.