Selection and evaluation of technologies for oil rim preparation of Zapolyarnoye oilfield

L V Vazhenina

Tyumen Industrial University, 38, Volodarskogo St., Tyumen, 625001, Russia

E-mail: Vagenina@rambler.ru

Abstract. The article deals with various technologies for the oil rims preparation of Zapolyarnoye oil and gas condensate field. The following circuits were considered for the selection of the technology of preparation of extracted fluid: low-temperature separation (STC); low-temperature condensation (LTC); low-temperature rectification (NTR); low-temperature absorption (LTA); membrane technology (Mt). Diagrams of these processes were collected and tested in the system HYSYS process simulation. Efficiency analysis of hydrocarbon raw materials preparation on the basis of functions, selection of components and narrow fractions.

Introduction
Zapolyarnoye oil and gas condensate field, discovered in 1965 and being developed since 2001, was selected as an object of the study. Zapolyarnoye field is located 60 km South-East of the village Tazovskiy and 220 km away from Novy Urengoi, and it is considered as a part of the West Siberian petroleum province. The development license is owned by OOO "Gazprom dobycha Yamburg". The reserves of gas make up more than 3.5 trillion m$^3$, those of gas condensate — about 60 million tons, and those of oil - 20 million tons. At the top of the Cenomanian deposits, there are about 2.6 trillion m$^3$ of gas, and in Valaginsky horizons - 735 billion m$^3$ of gas. In the international ranking of gas fields, Zapolyarnoye field is on the fifth place. The annual production amounts to 105 billion m$^3$.

When choosing a method of processing (preparation) of associated petroleum gas (APG), the main criteria are meeting environmental requirements and the economic efficiency, which, in its turn, depend on the performance of raw material, parameters of raw material and product flow (pressure, temperature), gas composition (and significantly on the content of hydrogen sulfide and other acidic components), as well as the requirements for the finished product, infrastructure, capital and operating costs, etc. Thus, in each case, the method of APG processing (preparation) is chosen individually [1, 2].

Technologies and methods
The purpose of the research is the choice of the most efficient and cost-effective technology field oil rims with the Zapolyarnoye gas condensate field.

For the selection of the preparation technology of extracted fluid, the following graphs were examined: low-temperature separation (STC); low-temperature condensation (LTC); low-temperature rectification (NTR); low-temperature absorption (LTA); membrane technology (Mt). Diagrams of these processes were collected and tested in the HYSYS system of process simulation. The analysis of the
efficiency of hydrocarbon raw material preparation on the basis of functions of selection of components and narrow fractions was conducted.

### Table 1. Brief characteristics of the investigated technology

| Low-temperature Separation (STC) | Low-temperature Condensation (LTC) | Membrane technology (Mt) |
|---------------------------------|-----------------------------------|--------------------------|
| 1. Cooling due to the throttle effect. | 1. Cooling due to the throttle effect and additional refrigerant. | 1. Sorption of gas molecules on the surface of the membrane from the partial mixture. |
| 2. The separation in the separator. | 2. Contact condensation in demethanization. | 2. The gas diffusion through the membrane. |
|                                 | 3. The separation of demethanization. | 3. Desorption of gas from the other side of the membrane surface. |

### Table 2. Comparative evaluation of the studied technologies

| Settings                        | Methods       | Results |
|---------------------------------|---------------|---------|
|                                 | STC           | LTC     | Mt      |
| 1. The yield of dry gas, ton/h   | 403.9         | 416.9   | 427.6   |
| 2. NC output, ton/h              | 128.2         | 115.1   | 104.5   |
| 3. The degree of purification    | low           | high    | average |
| of marketable gas                |               |         |         |
| 4. The efficiency of processing  | low           | high    | average |
|                                 | average       |         | low     |

### Table 3. The benefits and drawbacks of the investigated technology

| STC                              | LTC                        | Mt                        |
|----------------------------------|----------------------------|---------------------------|
| Advantages                       |                            |                           |
| 1. Simultaneously with the separation, the gas drying to dew points of the moisture and hydrocarbons occurs; | 1. sufficiently high degree of extraction of components C₃+above 95%; | 1. simplicity of design of the membrane apparatus; |
| 2. low capex and operating costs; | 2. small capital investmen ts; | 2. easy operation; |
| 3. easy operation and maintenance; | 3. easy operation; | 3. low energy costs; |
| 4. the ease of regulation and automation of technological process. | 4. flexibility of process | 4. possibility of formation of industrial gas separation systems. |

| Disadvantages                    |                            |                           |
| 1. dependence of extraction of target components on the composition of raw materials and free differential pressure; | 1. high energy costs; | 1. low permeability; |
| 2. a low degree of extraction of target components C₃+higher, especially for "skinny" gases; | 2. continuous decline of efficiency in operation. | 2. in some cases, low selectivity membranes; |
| 3. high losses of target components with product gas; | | 3. the need for a high technological culture in their production and operation; |
| 4. the reconstruction of the installation with the replacement of the cold source after the exhaustion of the free pressure drop; | | 4. the high cost of the membrane; |
| 5. the need to use a hydration inhibitor, which increases the process. | | 5. small lifetime. |
In the course of the scientific study, the technological schemes of the methods, their advantages and disadvantages were studied. Tables 1-3 show a brief description of technological schemes of the selected training methods.

**Research of oil rims preparation technology**

In the study, it was found that the most important criterion in the analysis of the methods of preparation of extracted fluid of the polar deposits is the efficiency of processing hydrocarbon raw materials, i.e. the distribution of components and narrow fractions of raw materials between the generated products. And the performance indicator will be the ratio of the selection.

It was decided to use the distribution of components and narrow fractions of raw materials between the resulting products as a very clear criterion of efficiency of any process of physical refining of hydrocarbons. To quantify this distribution, there is the concept of the sampling ratio. This method clearly characterized the clarity of separation of components of raw materials between products. Selection, obtained during the calculations and plotting, can be considered as a kind of "passports of efficiency" technologies.

The degree of purification of the gas is determined by the content of components C_{1+higher} of product gas; the higher the content of heavy hydrocarbons in the gas, the worse.

The efficiency of processing is characterized by the degree of steepness (slope) of the S – shaped curve – the flatter it is, the worse the efficiency of processing is (as the number of targeted products is diluted in the processed products). A graph showing the efficiency of technologies is presented in Figure 1.

**Figure 1.** Selection of hydrocarbons for processes of STC, LTC and membrane technologies

Preparation of the oil rim and gas condensate by NTA is a relatively complex process, as the number of devices (separators, condensers, heat exchangers, etc.), devices for automatic regulation, is two times more than that of other schemes. Moreover, the consumption of electro thermal energy is significant. Compared to STC, STC, technology LTA is a capital-intensive and costly process and, accordingly, is not economically advantageous.
The disadvantage of technology of low temperature distillation is that it is applicable mainly for the distillation of liquid hydrocarbon mixtures, and during separation of the multicomponent gas-liquid mixture. It is best to use this method in combination with others; that is, the combined method will be most beneficial.

There are many variations of the technology of STC, but the most promising and common is the diagram of the STC, with the turbo-expander and propane refrigerator. These schemes compared with with all others (LTC with propane and internal cooling loops; LTC with a cascading propane-ethane refrigeration cycle; LTC with a cascading propane-ethane refrigeration cycle and expander) are simple in hardware design and allow one to extract hydrocarbons C$_{3+}$higher and to reach the deep extraction of propane and heavier hydrocarbons, have flexibility in terms of the quality and quantity of feedstock [3].

The analysis of the advantages and disadvantages of the investigated technologies selected three technological schemes: STC, LTC, with turbo-expander and propane refrigerator, and membrane technology.

Raw material installations STC, LTC and membrane technologies are used to study the oil rim and condensate, produced directly from the field.

To prepare the oil rim of the polar deposits by the process of the low-temperature separation scheme, STC with two separators – input and low-temperature, and one separator were chosen.

All the schemes of preparation of the oil rim were built in HYSYS process simulation. Technological models are adequate to real existing objects. The built technology model was adapted to the measured parameters and indicators of modeling objects.

On the basis of technological schemes, constructed in the simulation system, the material balance of plants STC, LTC and membrane technologies was made up.

As a general and highly descriptive criterion of efficiency of any process of "physical" hydrocarbon processing, it is possible to use the component distribution and narrow fractions of raw materials between the produced products. To quantify this distribution, the sampling ratio is quite often used in practice, which refers to the mass fraction ( % ) component (narrow fractions) of raw materials, selected with its processing into one of the products [4].

For each of the selected technologies, the sampling ratio of components of the extracted raw gas and condensate field in the product gas was calculated.

On the basis of the dependence of selection coefficients of the individual components or narrow fractions on the temperature of boiling, let us build in the selection process for the three considered technologies, shown in figure 1. The selection process is depicted in the form of smooth monotonic S−shaped curves with varying degrees of steepness. The technology function of STC is significantly flatter than the functions of LTC and membrane technologies. As already mentioned, the more canopy the S− curve, the worse the effectiveness of training, as target components and fractions are washed away by the by-products. Hence, the target product of the preparation, which is dry gas, will contain components C$_{3+}$higher in its composition. Unlike STC, membrane technology and LTC have the most steep S−shaped curves that characterize the precise distribution of the components and narrow fractions of the raw material by products. The graph shows that the method LTC is the most effective process of preparing the oil rim of the polar deposits. Efficiency consists in achieving sufficient clarity and separation of the target components (fractions) by the products of individual processing.

Together with the curvature degree of the curve, describing the function of the selection, its important characteristic is the boiling point of a component (fraction), the selection rate of which is equal to 50%. Such component (narrow fraction) is actually a "key" component, uniformly distributed between liquid and vapor: lighter components are distributed mainly in pairs, the heavier the liquid. Therefore, this parameter is called the boiling point of a key component (Tk50). In fact, it sets the upper and lower bounds of the fractional compositions of emerging products [4].

In the sigmoid, there are two governing parameters — the slope coefficient (S) and the boiling point of a key component (Tk50). They quantitatively characterize the efficiency of the process. The S
parameter describes the efficiency of the process according to the criterion of selectivity of separation of hydrocarbons. Parameter T_{k50} shows the nominal limits of products boiling of the process.

A more specific value — specific increment of the selection rate \(dK/dT\) in wt. %/°C in the middle part of the selection process can be offered as a more visually appealing and intuitive criterion of selectivity of separation of hydrocarbons instead of an abstract of the slope coefficient sigmoid (S). This parameter is easily calculated using equation (1). Two values \(K_i\) when \(T_{ki} = T_{k50} + 0.5\) and \(T_{ki} = T_{k50} - 0.5\) are calculated; at that, the difference between the first and second values is a value of \(dK/dT\). The calculated values of the specific increments of the sampling ratio are also shown in table 4. Its growth, as well as the increase of the S parameter, corresponds to an increase of selectivity of separation of hydrocarbons, i.e. to the increase of the efficiency of the technological element. However, the specific increment more clearly characterizes the degree of efficiency, thus, its use is more preferable [4]. Next, let us calculate the slope coefficient of sigmoid S by the formula 1.

\[
K_i = 100 - 100/(1 + \text{EXP}(S \times (T_{ki} - T_{k50}))) \quad (1)
\]

Having factor S, it is possible to calculate the unit increment of each technological process, which will most clearly describe the degree of effectiveness. All results are summarized in table 4.

**Table 4. The calculation of unit increment of studied technologies**

| Sigmoid parameters | Products (Oil condensate) | STC | LTC | Mt |
|--------------------|--------------------------|-----|-----|----|
| \(T_{k50}\)        | -54                      | -26 | -30 |    |
| The slope coefficient | 0.0129                   | 0.0484 | 0.0349 |    |
| \(dK/dT, \%/°C\)   | 0.321                    | 1.212 | 0.872 |    |

The calculated slope coefficient S and the specific increment reaffirm the effectiveness of the technology of LTC. The content of components \(C_{3+}\)higher in the dry gas method LTC is less compared to that of STC and membrane technologies. Based on the calculations and the graph, the technology of low-temperature condensation is the most effective circuit training Zapolyarnoye field. Membrane technology is a relatively new process for the preparation of hydrocarbons. It has a number of advantages, but its main drawback is the small life of a membrane unit, which within a certain period requires the replacement of the module, which will increase the process. The installation of STC in comparison with other technologies is the most expensive, but the quality justifies the price of dry gas. Dry gas supplied to the gas pipelines, must have certain chemical and physical properties. Otherwise, it may have a number of problems: the reduction in the pipeline throughout the capacity increase of the power drive of compressors for gas compression, erosion, corrosion and premature wear of the pipeline, a blockage of control measuring and regulating devices, environmental pollution in the purging and cleaning of pipelines, accidents. All this leads to deterioration of technical and economic indicators like raw material extraction and processing, and trunk transportation of gas. Properties of a gas depend entirely on its composition, and the composition of the resulting gas depends largely on the choice of the technological scheme of preparation. Therefore, it is necessary to determine the most economically advantageous method of preparation of extracted fluid.

Comparative evaluation of the effectiveness of the studied technologies in a production environment is shown in table 5.

**Table 5. Comparative evaluation of the effectiveness of the studied technologies**

| Settings | STC | LTC | Mt | Evaluation of compared technologies |
|----------|-----|-----|----|-------------------------------------|
|          |     |     |    | LTC to Mt                           |
|          |     |     |    | LTC to STC                          |
| abs.     |     | abs. |    |                                     |
| %        |     |     | %  |                                     |
1. Annual capacity, thou. m³
   - dry gas: 4255.9, 4393.1, 4505.6, -112.5; capital investments for the installation, mln rub: 600, 1350, 1080, 270, 25, 750, 125
   - oil condensate: 4393.1, 38418, 27976, 442, 1.6, 4193, 17

2. Capital investments for the installation, mln rub
   - dry gas: 600, 1350, 1080, 270, 25, 750, 125
   - oil condensate: 1350, 307.3, 239.7, 67.6, 28, 166.4, 118

3. Capital intensity, rub/ton
   - dry gas: 4255.9, 4393.1, 4505.6, -112.5; capital investments for the installation, mln rub: 140.9, 307.3, 239.7, 67.6, 28, 166.4, 118
   - oil condensate: 140.9, 3.3, 4.2, -3.8, -0.5, -0.9, -0.2

4. Capital logica, ton/rub
   - dry gas: 7.1, 2.5, 137.2, 3.2
   - oil condensate: 7.1, 3.3, 4.2, -3.8, -0.5, -0.9, -0.2

5. The yield of the target product
   - dry gas, thou. m³: 4255.9, 4393.1, 4505.6, -112.5, 2.5, 137.2, 3.2
   - oil condensate, thou. ton: 1061.8, 953.2, 864.9, 88.4, 10.2, -108.6, -10.2

6. Revenue from product sales, thou. rub
   - dry gas: 24225, 28418, 27976, 442, 1.6, 4193, 17
   - oil condensate: 4247236, 3812932, 3459492, -434304, -10.2, 353440, 10.2

**Conclusion**

In the assessment of efficiency of scientific research, it was found that the specific capital intensity of membrane technology is the most beneficial. The price of the membrane module is more acceptable, but its main drawback is the small operation lifetime of 4 - 5 years and, depending on the composition of the raw material, it significantly increases the cost of periodic replacement. The main criterion for any technology of preparation of hydrocarbon raw materials is the quality of the target product. The quality of dry gas produced by the membrane technology is inferior to the quality of dedicated dry gas, according to the technology of LTC, which is evident from the graphical dependence (figure 1) of the effectiveness of technological schemes for the separation of components or narrow fractions of the incoming stream between the outcoming ones. Taking into account the quality of the target product, the price will be correspondingly higher; hence, the revenue per unit of product will increase. Taking into account the entire efficiency calculation, it is possible to conclude that the technology LTC is the most appropriate scheme for the preparation of the oil rim of the polar deposits.

**References**

[1] Adzhiev Y A, Purtov P A 2014 *Preparation and processing of associated petroleum gas in Russia: scientific publication* (Krasnodar: ADVI) p 776

[2] Dynarski Y I 2007 *Basic processes and apparatuses of chemical technology: teaching in the expedient design* (Moscow: Publishing house Alliance) p 328

[3] Kasperovich A G, Magaril R Z 2008 *Balance calculations in the design and planning of hydrocarbon processing and gas condensate oil and gas condensate fields: a tutorial* (Moscow: KDU) p 412

[4] Information-analytic review 2008 *The fuel and energy complex of Russia. 2000-2007* (Moscow: Publishing analytical centre Energy) p 432

[5] Vazhenina L V 2011 *Associated petroleum gas: experience of processing and performance evaluation: a monograph* (Tyumen: Tyumen oil and gas University) p 216

[6] Vazhenina L V 2012 *Napravleniya Povysheniya Energoeffektivnosti v magistral’nom transporte gaza: a monograph* (Tyumen: Tyumen oil and gas University) p 280

[7] Vazhenina L V 2015 *Project Management of Strategy for Energy Efficiency and Energy Conservation in the Gas Sector of the Economy* *Studies on Russian Economic Development* 26(1) 39–48