An Integrated Approach to the Development and Reservation of Gas in Central Yakutia

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Abstract. The article provides a detailed overview of diverse problems in gas industry in the Central part of the Republic of Sakha (Yakutia). The problems associated with the provision of recoverable gas reserves, seasonal contrast of produced amounts, production and gas transportation system and the challenges of increasing the gas consumption market are considered in details. A retrospective assessment of the initial geological reserves of natural gas of the Middle-Viluy gas condensate deposit is given. On the basis of production characteristics of deposits and the analysis of development of the worked-out deposits, coefficient of recovery of gas is estimated. It is concluded that under the current system of development of the Middle-Viluy gas condensate deposit, the ratio of the ultimate gas recovery will amount to just 0.5. The inexpediency of construction of boosting compressor station for production of several billion cubic meters of gas is shown. An integrated approach to solving the existing problems of the gas industry is proposed. The necessity of reserving gas raw materials in close proximity to the consumer by creating an subsurface gas storage is noted. It is concluded that only the creation of a gas reservation system will allow to extract most efficiently gas resources of the Central Yakutia and provide the necessary level of energy security.

1. Introduction

Gas is the only energy supply source in Central Yakutia, where there is more than 40% of population of the Republic of Sakha (Yakutia). Gas-condensate deposits (GCD) of the Viluy oil-gas-bearing area (OGBA) with ultimate in place reserves over 440 billion m³, are the source of raw materials. At the same time, about 1.6 - 1.7 billion m³ of natural gas is extracted for needs of Central Yakutia. At first sight, this provides confidence in complete and final provision of all consumers with natural gas over the long term. This all makes it possible to expand gas supply network, to plan large projects, which will use significant amounts of natural gas.

Advantages of energy supply of industrial and household purpose cannot be emphasized, which is almost completely realized with natural gas, in comparison with other traditional sources of energy (oil, coal, firewood etc.).

At the same time, serious different problems, related to gas transportation system, dispersion and provision of active reserves, imperfection of production and increase of gas consumption market, are possible.
2. Problem statement
The Viluy OGBA includes deposits, mainly confined to the Khapchagaisky and Loglorsky ramparts of the Viluy syncline of the Siberian platform[1]. The Middle-Viluy GCD (western part of the Khapchagaisky rampart, brought into development in 1986, is the main and only one source of gas supply of Central regions of Yakutia at this time. Until recently, three wells of the Mastakhskoesky GCD were operated (with quite small amount, $\approx 100$ million m$^3$) for leveling peak amounts of gas production of the Middle-Viluy GCD in wintertime.

While in place reserves of the Viluy OGBA are significant, main concern to consumers is the fact, that they are dispersed over large area as small gas occurrences. At the same time, only 2 deposits of 9 ones: Middle-Viluy and Srednetungskoe, can produce gas in current amounts 10 million m$^3$ a day and more (peak winter consumption). Srednetungskoe GCD is situated at big distance from operating gas pipelines ($\approx 180$ km in a straight line), and its connection is an objective for the far future. All other deposits have low potential for gas production, and in case of intensive development they can follow example of the Mastkhsaky GCD: early water encroachment of operating wells, which led to low gas recover factor [2, 3]. Under given conditions, the Middle-Viluy GCD remains the main gas supply source for a foreseeable future (10-15 years). This underlines the importance of determination of feasible opportunities of gas production of the Middle-Viluy deposit for complete production of its residual reserves.

Secondly, in the Middle-Viluy GCD, there is a problem of pronounced seasonal contrast of gas production due to heat generation during the heating season (variation factor – 0.6). Such contrast of gas production is undesirable in terms of efficient development, creating real risks of gas loss (due to stoppage of gas discharge) and condensate dropout in a layer (when reservoir pressure drops lower dew point), early water encroachment of the gas occurrence in zones of better reservoirs etc. [4, 5].

Thirdly, gas pipeline network of 466 km represents 3 main gas pipelines (MGP), two of them have wear 100 and > 65%. Third MGP is not completed at 80 km distance from the Middle-Viluy GCD. All these aspects cause increased risks during gas transportation, that is confirmed by emergency situations and incidents.

In addition, questions remain regarding organization of production, specification of gas recovery factor (GRF) with existing technological approaches etc. Practice of foreign and Russian gas production shows that, GRF may vary within wide range (0,4-0,95) depending on numerous objective factors [6-10].

3. Experimental part
In place reserves of gas of the Middle-Viluy GCD were estimated many times. When considering history of the study and approval of in place reserves of gas of the Middle-Viluy GCD, three recalculation stand out. Firstly, approval of in place reserves of free gas in the State Commission of Reserves (SCR) (protocol №6133, dated 1 5.01.1971) is noted, which accepts an amount 166 billion m$^3$ on horizons $T_1$-IIa, $T_1$-IIZ and $T_1$-III. This is followed by recalculation of gas reserves accepted by the State Committee on Reserves (CCR) (protocol №105, dated 20.12. 2000), where the amount of 144 m$^3$ on these layers is determined. Recently, protocol of the Ministry of Natural Resources (MNR) №18/197, dated 21.03.2012, on producing horizons $T_1$-IIa, $T_1$-IIZ and $T_1$-III B, accepted the amount of reserves of “dry gas” as 158 billion m$^3$, and total amount of the deposit – 162 billion m$^3$. Not distributed reserves of free gas (gas reserves of the area beyond license site) are additionally presented, in amount equal to $\approx 18$ billion m$^3$. Total reserves of the Middle-Viluy deposit, in this case, are 180 billion m$^3$, and reserves on the main mining levels $T_1$-IIa, $T_1$-IIZ and $T_1$-III will be 176 billion m$^3$. It should be noted that, recalculation, dated 2000 (CCR protocol №105, dated 20.12.2000) under the supervision of Shabalin V.P., who studied the Middle-Viluy GCD from the very beginning of its exploration, on competent and liable level, may be not far from the truth. Recalculation, dated 2000, decreases reserves by 13,5% contrary to accepted in place reserves by SCR in 1971, and by 18,4% of the late estimations in 2012. Note that, Shabalin V.P. was one of the main executors in the report on reserve estimation in 1971.
Although a small amount of exploration has already been carried out, the Tolonskoe and Sobolokh-Nedzhelinskoe deposits, located in the MGP area, are remarkable by complex geological structure [11-13]. Preparation for operation and maintenance phase of these two deposits will require tremendous investments, and will have to consider their separation for numerous gas occurrences.

At first approximation, we will consider production possibilities of the Middle-Viluy GCD without booster compressor station (BCS). Deposit development without BCS, is carried out using layer energy – reservoir pressure. Operation of the Kysyl-Syr – Yakutsk MGP is constrained in using linear CS – compressor stations. This leads to the need for maintain pressure in the initial part of MGP – not less than 6,0 MPa. Only in this case, pipe pressure reaches necessary level of 3,0 MPa in the terminal part of MGP (Yakutsk). Hence, reservoir pressure in the gas occurrence should be not less than 9,0-10,0 MPa in order to maintain pressure in the well mouth of the Middle-Viluy GCD on the level of 6.0 MPa, because pressure of stationary gas column, with a layer depth 2500 m, will be not less than 3,0 MPa. At the same time, stable operation of the well, when liquid outflow is possible on the wellbore of the tubing string, can be maintained if gas yield is not less than 80-1000 thousand m$^3$/day. This mode of minimum operation yield of the well is possible only in case of reservoir pressure in the gas occurrence within 12,0-13,0 MPa. These pressure values are condition for the final stage of the deposit development aimed to gas depletion.

Table 1. Estimates of initial reserves of the Mastakhskoeskoe GCD and gas recovery factors on horizons [2].

|          | Initial reserves. SCR USSR. A+B+C$_1$ | Initial geological reserves. CCR Gazprom A+B+C$_1$ | Reserves evaluated by method of pressure drop A+B+C$_1$ |
|----------|--------------------------------------|----------------------------------------------------|-----------------------------------------------------|
|          | million m$^3$                         |                                                    |                                                     |
| T$_1$-IVa| 1097                                 | 6058                                               | 2277                                                |
| produced | 1977                                 | 1977                                               | 1977                                                |
| residue  | -880                                 | 4081                                               | 300                                                 |
| % recovery| $180.2$                              | $32.6$                                             | $86.8$                                               |
| J$_1$-I  | 20165                                | 15647                                              | 10850                                               |
| produced | 6911                                 | 6911                                               | 6911                                                |
| residue  | 13254                                | 8736                                               | 3939                                                |
| % recovery| $34.2$                                | $44.1$                                             | $63.7$                                               |
| P$_2$-I  | 7221                                 | 589 2                                              | 5962                                                |
| produced | 1962                                 | 1962                                               | 1962                                                |
| residue  | 5259                                 | 6530                                               | 3928                                                |
| % recovery| $27.1$                                | $23.1$                                             | $33.3$                                               |
| T$_1$-X(west) | 6651                               | 6928                                               | 1660 (+716=2376)*                                   |
| produced | 979                                  | 979                                                | 979                                                 |
| residue  | 5672                                 | 5949                                               | 681 (1397)*                                         |
| % recovery| $14.7$                                | $14.1$                                             | $58.9 (41.2)*                                       |
| T$_1$-X(east) | -                                  | 1847                                               | 1970                                                |
| produced | 1322                                 | 1322                                               | 1322                                                |
| octarok | 535                                  | 648                                                |                                                     |
| % recovery| 71.5                                  | 67.1                                               |                                                     |

* with regard to the eastern block, not put into operation
In turn, maintenance of gas pressure of 6 MPa in initial part of MGP, restricts gas recovery factor (GRF). Original reservoir pressure in the Middle-Vilyui GCD was 25,0 MPa, and half of this value will be respectively 12,5 MPa. So, we can expect GRF 0,5, in case of gas mode of the layer production. In this case, in place reserves of free gas on the main producing horizons T1-IIa, T1-IIb and T1-III, which reach amounts of 160-170 billion m³, at final stage of the deposit development should be close to amounts of 80-85 billion m³ to 95-100 billion m³ of recoverable gas. Accordingly, on 01.01.2020, when accumulated gas production reaches 42 billion m³, residual recoverable gas reserves will be close to 50-50 billion m³. This amount of recoverable gas forms actual mineable gas reserves for the nearest future in Central Yakutia. In fact, GRF values of the worked-out Mastakhskoe GCD confirm above-mentioned discussions (table 1). Analysis of the Middle-Vilyui GCD development also show low activity of the bottom waters [14]. It is concluded that, compensation of the reservoir pressure decrease when the bottom waters are intruded, is practically not shown.

At the same time, the global practice of gas deposits production shows a regular decrease in reservoir pressure at all stages of production and, accordingly, a decrease in production capacity. Therefore, it is necessary to take into account that production of only the first half of the allocated volume of recoverable gas reserves (25-30 billion m³) will be able to fully ensure the gas consumption in the central regions of Yakutia during the winter «peak» period. The current annual gas consumption in the region in the amount of 1,6 billion m³ can be maintained for maximum 15 years. After this period, mining capacity when withdrawing the second half of the aforementioned recoverable reserves might turn out not sufficient. Then it will be necessary to drill an additional number of production wells in the Middle Vilyui GCD (Gas Condensate Deposit) or to join into production a new gas deposit as a regulator. In other words, there could be problems in gas supply of Central Yakutia in 10-15 years that can be solved by increasing the production capacity of the Middle Vilyui GCD or by arrangement of a new deposit. In addition, imperfection of production well pattern, as well as a long period of uneven gas extraction due to the delay of communications arrangement when crossing the Vilyui River, and a seasonal contrast of production may significantly approximate the forenamed problems [2].

Based on the foresaid production problems and the situation with the prepared recoverable gas reserves, we consider it necessary to emphasize that any attempts to significantly increase gas production from the Middle Vilyui GCD to use it for other needs will result in high risks for the gas supply of Yakutsk and its environs.

When planning investment projects, it is necessary to take into account that the production of other deposits of the Vilyuiisk OGBA will require huge investments, sometimes incommensurable with the gas reserves it has.

Production of deposits using the BCS (Booster Compressor Station) allows to reduce pressure at the mouth of production wells up to 1,0-2,0 MPa. This method makes possible to extend the time of well operation and significantly increases gas production amount, which consequently increases the GRF indicators during the deposit production. BCS is a complex and very large construction that requires a huge investment. The BCS construction cost will be comparable to the one of all the Middle Vilyui GCD arrangement. According to the Russian experience, the BCS construction is profitable in case of residual reserves in the range of 0,5-1,0 trillion m³. In any case, it is obvious that it is hard to justify the construction of the BCS for extraction of a few tens of billions of gas m³.

To date, the reliability of natural gas transportation from the Middle Vilyui GCD is ensured by a triple main gas pipeline Middle Vilyui GCD – Mastakhskoe GCD – Berge filed – Yakutsk. Of the three lines, the first one is worn on 100%, the second one is more than 65%. The third line was built only to the worked-out Mastakhskoe GCD, and another 80 km are to be built to the main Middle Vilyui GCD. It is obvious that the increased wear of gas pipelines, technological accidents that were there [15-17] and the increasing risks of the new ones need the urgent salvation of the problem of ensuring the reliability of existing gas transmission facilities operation.

In this case, the shortcomings of the regional specificity are fully reflected in the «source-consumer» scheme closed gas supply system. Herewith, winter daily gas consumption is almost two times higher than the average annual one and almost three times than that of the summer period.
4. Results and discussion

The construction features of arrangement of deposit and gas transportation system are also designed for the specified gas consumption at maximum loads. Consequently, in summer and intersessional time, all these capacities are about half unclaimed. These features of gas supply systems apply for the most areas with moderate climatic conditions throughout our country and in the world. The problems are successfully solved by creating centralized gas transportation systems and gas reservation in the UGS (Underground Gas Storage).

We considered the limitation of gas reserves of the Middle Vilyui deposit thoroughly in this article, therefore the question of connecting other deposits is inevitable. There are several gas condensate deposits in the area of the operating main gas pipelines on the right bank of the Vilyui River, with total gas reserves exceeding 250 billion m$^3$.

However, all these deposits, including the Middle Vilyui GCD, each separately, are not able to ensure maximum seasonal gas consumption of the central regions of the republic in a not too distant time (15 years).

The problem of covering maximum production amounts for many years can be solved by creating UGS in the vicinity of Yakutsk. UGS with a buffer gas volume of just 2-3 billion m$^3$ can provide all the annual gas consumption (1.6 billion m$^3$) in Central Yakutia.

It is also obvious that the presence of the UGS near the consumers themselves will have invaluable advantages at the closed gas supply system. Not to mention the complete removal of the gas transportation system problem in case of emergency situations and a significant simplification of arrangement of the subsequent gas production facilities. The emerging of the gas storage operator will allow to develop small deposits, even the individual productive wells of depleted deposits. It will relieve us of the seasonal highs of gas production by means of its even distribution throughout the year. Gas, accumulated over the summer period, can be used at the time of maximum consumption in winter.

The UGS use in the gas supply scheme in Yakutia will certainly be in demand in the future. The whole gas industry of the World is developing along this path. Given the fact that the nearest regions with the hydrocarbon sources are away from Central Yakutia for at least 1000 km, we can certainty say that there is no alternative to reserve natural gas in the vicinity of Yakutsk.

The main criteria for the planned Yakutsk UGS places selection should be: proximity to the main consumers and the main pipe, as well as the optimal depths. The optimum depth is the one, where the amount of the buffer gas is more than 50% (depth interval is 1300-1700 m). Bigger depths require big capital investments. It makes sense to combine the search of the UGS location with the search of the new deposits in the nearest promising areas, given the absence of localized, contrastingly isolated and studied structures near Yakutsk and in the location of the main gas pipeline corridor Middle Vilyui GCD – Mastakhskoe GCD – Berge deposit – Yakutsk. The geological prerequisites for the discovery of small deposits in vicinity of Yakutsk city are described in detail in the works [18-22].

5. Conclusions

Geological reserves of gas in the Vilyui oil-gas-bearing area are spread over a large area. The deposits, discovered here, are distinguished by a complex geological structure and consist of many small deposits in various stratigraphic levels.

We presented the estimates of the initial geological reserves of the Middle Vilyui GCD gas of various years and that of the recoverable gas volumes without the use of the BCS. We noted that the GRF is expected to be no higher than 0.6 with the existing system of gas transportation features and production in Middle Vilyui GCD. We concluded that the deposit can maintain the current level of gas production for a maximum 15 years.

We showed the inexpediency of the BCS usage in the Middle Vilyui GCD and the need to join the Khapechagay rampart other deposits into the main gas pipeline. We highlighted the problems and risks of the Middle Vilyui GCD deposits and that of the existing gas transportation industry.

We propose to organize the UGS in the vicinity of Yakutsk to solve the whole complex of problems, which will allow:
- solve the problem of the marked seasonal contrast of production in the Middle Vilyui GCD due to the usage of the UGS facilities in winter and the planned filling of the UGS facilities in summer.
- join other deposits of the Khapchagay rampart to fill the UGS, which will allow to develop the Middle Vilyui GCD in a sparing mode.
- reduce risks in cases of the non-standard situations in the Kysyl-Syr – Mastakhskoe – Berge – Yakutsk main gas pipeline.
- make confident management decisions on expanding the gas consumption market and increase the investment attractiveness of the gas resources of the Vilyui oil-gas-bearing area.

Creating the UGS facility and reserving natural gas for gas supply of Yakutia Central Industrial Region might open a new era in the gas industry development and, consequently, in the entire power economy of the region at a modern technological level.

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