Analysis of the application of a chemical method for preventing hydrate formation on the example of the Novo-Chaselskoye field

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Abstract. In the presented work, the possibility of preventing the formation of gas hydrates at the Novo-Chaselskoye field by means of metered methanol injection is considered. The current state of field development and information on reserves are presented. A method for calculating the amount of an inhibitor (methanol) required to prevent hydrate formation for Cenomanian gas is presented. As a result of the study, the amount of methanol consumption for hydrate-free well operation was calculated, the conditions and places of possible hydrate occurrence were analyzed, and the required amount of hydrate formation inhibitor was calculated to be supplied to the wellhead to prevent hydrate precipitation.

1 Introduction

Deposits of natural gas hydrates have an extremely negative effect on the collection systems of borehole products of gas, gas condensate and gas oil fields, as well as on internal technological piping systems and gas treatment devices. The operation of the gas transmission system in a hydrate regime leads not only to the risk of deposits of natural gas hydrates, but also to changes in the operating modes of gas treatment plants due to changes in the flow section of pipelines, and in the worst case, this is clogging of pipelines, fittings and equipment at oil and gas production facilities and linear part and on–site facilities of main gas transport, including including at underground gas storage stations.

To prevent the formation of gas hydrates in production, collection and treatment systems, as well as in main pipeline transport systems, hydrate formation inhibitors of various types are used, however, methanol or, in some cases, glycols are currently used in the conditions of the Far North. Despite significant experience in the use of methanol to prevent hydrate formation, problems remain unresolved related to the excessive consumption of methanol and the production of products that do not meet the standards for the content of dissolved methanol. These problems can be successfully solved by improving the technological scheme of gas treatment through the introduction of more efficient technologies.

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2 Methods and Materials

In this section, it is necessary to describe the materials and methods that you used when writing the article (conducting research). According to the technological scheme for the development of the Cenomanian and Turonian deposits, the PK_1 gas reservoir of the Novo-Chaselskoye field has been in trial operation since 2009 with wells 220p, 221p, 223p and 228p, production is utilized for its own needs [1].

As of 01.01.2021, a total of 14 exploration wells were drilled at the field, including 4 wells in operation for the gas field (2 wells (223r, 228r) are in operation, 2 wells (220r, 221r) are stopped), 7 wells are in conservation, 3 have been liquidated.

The operation was carried out for 29 months with an average sampling of 5.42 million m3/month. The operating coefficient is 0.29. The selection of geological reserves of free gas of category C1 of the PK_1 formation amounted to 0.337%, deposits – only 0.233%.

The current gas flow rate was 155 thousand m3/day. The PK1 gas reservoir is one of the main ones in the field: it accounts for about 42% of the geological reserves of gas of category C1+C2 or 59% of category C1 (Figure 1).

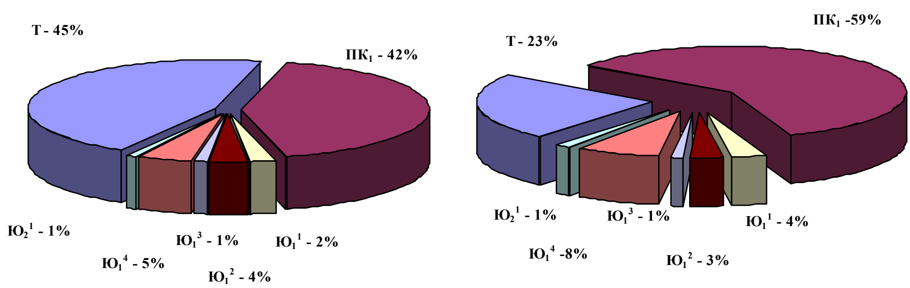

Fig. 1. Distribution of geological reserves (%) by strata of the deposit.

The dynamics of the Novo-Chaselskoye field development is shown in Figure 2.

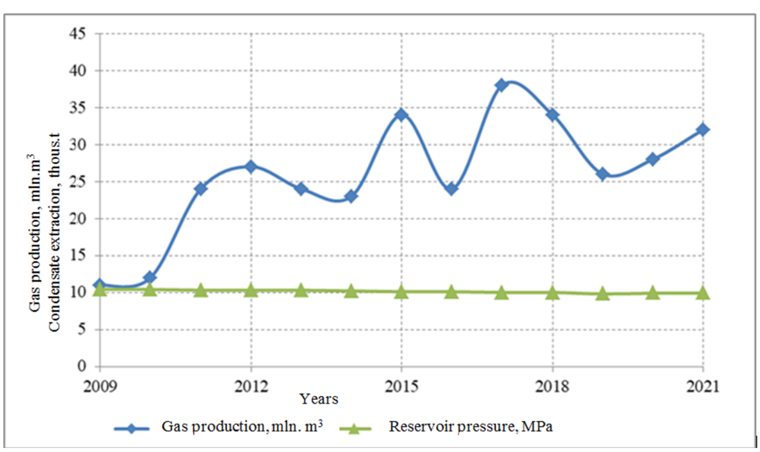

Fig. 2. Dynamics of the Novo-Chaselskoye field development indicators (PK_1 formation).

The result of the methods described above to combat the formation of hydrates in the wellbore at the Novo-Chaselskoye field in 2020 is an increase in gas flow rate in wells at bush No. 288, shown in Table 1.

Table 1. Actual results after the implementation of measures to combat hydrate formation.

Well number	Well flow rate before the event, thousand m^3/day	Well flow rate (after inhibitor injection), thousand m^3/day	Well flow rate (after using an electric heater), thousand m^3/day	Well flow rate (after thermal erosion of a solid hydrate plug), thousand m^3/day	Flow rate growth, thousand m^3/day (%)
564	344	450	-	-	106 (30.8%)
654	310	-	-	380	70 (22.6%)
656	315	-	390	-	75 (23.8%)
764	380	520	-	-	140 (36.8%)

3 Results and Discussion

After analyzing the data presented in Table 1, we can see that the most effective method in terms of hydrate control at the Novo-Chaselskoye field is currently the method of injecting an inhibitor (methanol) into the borehole [10, 14-15].

Based on the fact that the consumption of methanol in the warm season decreases sharply, we conclude that it can be neglected. This process is associated with an increase in the temperature of the air and the environment, so the calculation will be carried out in the cold [5]. From the wells of bush No. 288 to UKPG-3C, gas with a density of p= 28.87 kg/m^3 is transported. Pressure at the wellhead of Ru = 7.7 MPa, temperature T_1 = 283 K.

During transportation, the gas is cooled to T2 = 273.4 K. Gas pressure at the inlet to UKPG R_k = 8.8 MPa. To prevent hydrate formation, an X_1 = 95% methanol solution is fed into the plume. It is necessary to determine the consumption of methanol G used in the implementation of a centralized methanol injection scheme [6-9, 11, 16]. The initial data for determining the consumption of methanol are presented in Table 2.

Table 2. Initial data.

Parameter Value	Parameter Value
Gas density, kg/m^3	28.87
Wellhead pressure, MPa	7.7
Temperature at the mouth, K	283
The temperature at the entrance to the UKPG is 3C, K	273.4
Gas pressure at the inlet to the UKPG-3C, MPa	8.8
Methanol solution in percentage, %	95

The following is a step-by-step algorithm for calculating the amount of methanol.

The calculation of the amount of methanol required for the hydrate-free operation of the wells of kust No. 288, field pipelines and the Novo-Chaselskoye field is carried out according to STO Gazprom 3.1 -3-010-2008 [3,4]. In the wells of the Novo-Chaselskoye field, conditions for the removal of condensation water are implemented. Therefore, reservoir conditions are chosen for point 1, the "protected" point 2 is located at the end of the plume (in front of the entrance of the BVSHIZR UCP) [2, 17]. There is no outflow of reservoir water by wells, i.e. G = 0. The following relationship between pressure and temperature is used for the Cenomanian gas of the Novo-Chaselskoye field:

$$\ln(p) = 31.5582 - \frac{8360.19}{T}. \tag{1}$$

At p = 10 MPa (reservoir conditions) The equilibrium temperature of hydrate formation is T = 285.76 K = 12.7636 °C; at p = 8.8 MPa (maximum pressure in front of the BSHiSR) the equilibrium temperature of hydrate formation is T = 285.76 K = 11.5204 °C; at p = 7.7 MPa (minimum pressure before BHP), the equilibrium temperature of hydrate formation is T = 285.76 K = 10.2332 °C; for the "protected" point 2, we will determine the conditions p = 8.8 MPa that are most conducive to hydrate formation and meet the Standards of the technological regime. The difference between the equilibrium temperature of hydrate formation at point 2 and the minimum temperature at the entrance to the BSHiZR of the UCP (+1 °C): ΔT = 10,5204 °C.

The minimum concentration of methanol in the liquid phase at the point 2 X_2, % wt. necessary to prevent hydrate formation is equal to:

$$\Delta \mathrm{T} = -A ln \frac{100 - X_2}{100 - 0.4378 X_2}, \quad (2)$$

Where A – an empirical coefficient depending on the gas pressure, its composition and the structure of the hydrates formed.

For natural gases forming hydrates of structure I (for gases from Cenomanian deposits of gas fields in Western Siberia), the calculation of parameter A is carried out according to the formula:

$$A = 81 - 0.22 X_2 + 0.005 X_2 (\mathrm{p} - 7.5). \quad (3)$$

After the transformations, we obtain a transcendental equation that can be solved in any mathematical way (for example, by the method of successive approximations):

$$\frac{10.5204}{ln \frac{100 - X_2}{100 - 0.4378 X_2}} + 0.2135 X_2 - 81 = 0. \quad (4)$$

As a result of solving this equation, it turns out that the value ΔT = -10.5204 °C it is achieved at a methanol concentration X_2 = 62.345 % mass.

Molar fraction of methanol X and its mass concentration $X_{масс,}$ % mass., are related by the conversion ratio:

$$\mathrm{X}_{mass} = \frac{3200\mathrm{x}}{18 + 14\mathrm{x}}, \mathrm{X} = 0.48222. \quad (5)$$

The moisture content of natural gas in equilibrium with pure water W_0, kg / 1000 m^3, is calculated according to the dependence:

$$W_0 = \frac{0.09984 z}{p} exp\left(18{,}3036 - \frac{3816.14}{T - 46.13}\right) \cdot exp\left(\frac{18p}{RT} + \frac{2 b_{\text{см}} p}{zRT + a_{\text{см}} b_{\text{см}} p}\right), \quad (6)$$

Where z – compressibility factor of the gas mixture; p – pressure, MPa; T – temperature, K; R – universal gas constant, R = 8,31 J/(mol·K); $a_{см}$, $b_{см}$ – coefficients calculated by formulas:

$$a_{\text{см}} = \sum_i a_i y_i, \quad (7)$$

$$b_{\text{см}} = \sum_i b_i y_{i,} \tag{8}$$

Where y_i – the molar fraction of the component of the gas mixture; a_i, b_i – empirical coefficients for the i – th component of the gas mixture.

The compressibility coefficient of the gas mixture for the Cenomanian deposit of the Novo-Chaselskoye field is assumed to be 0.9 according to the Brown and Katz curves (Figure 3) [12].

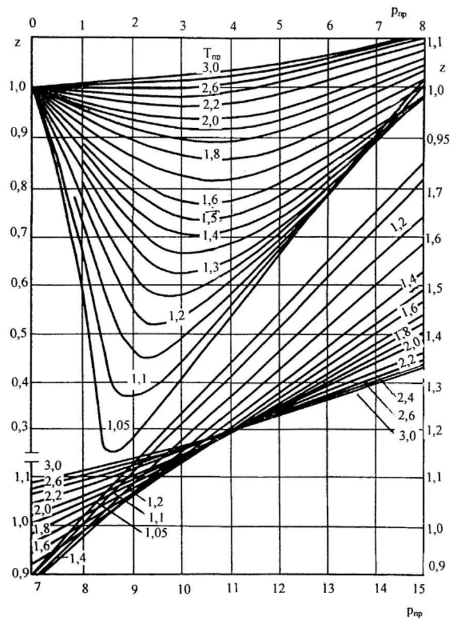

Fig. 3. Brown and Katz curves.

After calculation, we obtain the moisture content of natural gas at equilibrium with pure water W_0:

- In reservoir conditions W_1 = 0.3956 kg / 1000 m^3.
- In conditions of entry into the BHViZR UCP W_0 = 0.0875 kg / 1000 m^3.

The saturated vapor pressure of methanol p_s is calculated using the Antoine equation:

$$p_s = exp\left(18.5875 - \frac{3626.55}{T - 34.29}\right) 1.3332 \cdot 10^{-4} = 0.0042 \tag{9}$$

The empirical coefficient β is calculated according to the dependence:

$$\beta = -exp(7.9154 - 0.01145T) = -118.878. \tag{10}$$

The molar fraction of methanol in the gas phase y is calculated according to the following dependence:

$$y = \frac{p_s}{p} exp\left[\frac{2p}{RT}\left(\beta - \frac{V_{ж}}{2}\right)\right], \tag{11}$$

Where p_s – saturated vapor pressure of methanol, MPa; p – pressure, MPa; R – universal gas constant; T – temperature, K; β - an empirical coefficient having the meaning of the second virial coefficient, cm^3; V_j = 38,07 – molar volume of methanol, cm^3/mol; y = 0,00016586 – the molar fraction of methanol in the gas phase at the entrance to the BSHiZR of the UKPG.

The methanol content in natural gas, in equilibrium with pure methanol, is calculated by the formula:

$$Q_0 = 1331.31y = 0.2208 \text{ kg/1000 m}^3. \tag{12}$$

The content of methanol in natural gas, in equilibrium with aqueous solutions of methanol Q kg/1000m^3 calculated by the formula:

$$Q = Q_0 a_2 = 0.124757 \text{ kg/1000 m}^3 \tag{13}$$

Q - the content of methanol in the gas phase at the entrance to the BVSHIZR of the UKPG.

The minimum required specific consumption of the methanol inhibitor G kg / 1000 m3 is calculated by the formula:

$$G = \frac{G_1(X_2 - X_1) + (W_1 - W_2)X_2}{X_1 - X_2} + \frac{100 - X_2}{X_1 - X_2}[(Q_2 - Q_1) + (q_2 - q_1)], \tag{14}$$

Where G_1 – the amount coming from the previous technological section to point 1 in one liquid phase, kg/1000 m^3. If point 1 coincides with the first section of the methanol supply G_1 = 0. X_1, X_2 – the concentration of methanol in the aqueous phase before point 1 and at point 2, respectively , % mass. X_1 = 0, if there is no methanol supply before point 1, X_2 = 62.345 % mass. ; X – the concentration of methanol supplied to point 1, % by weight. X = 95%; W_1, W_2 – the equilibrium moisture content of the gas at points 1 and 2, kg / 1000 m^3. W_1 = 0.3956 kg/1000 m^3, W_2 = 0.04595 kg/1000 m^3; Q_1, Q_2 – the content of methanol in the gas phase at points 1 and 2, kg/1000 m^3. Q_1 = 0 kg/1000 m^3, Q_2 = 0.124757 kg/1000 $м^3$; q_1, q_2 – the methanol content in the hydrocarbon condensate at points 1 and 2 kg/1000 m^3. $q_1 = q_2$ = 0 кг/1000 $м^3$.

After simplification, it turns out:

$$G = \frac{(W_1 - W_2)X_2}{X_1 - X_2} + \frac{100 - X_2}{X_1 - X_2} Q_2 = 0{,}811 \text{ kg/1000 m}^3. \tag{15}$$

Taking into account the 15% reserve, we obtain the necessary specific consumption of an inhibitor (methanol) for hydrate-free operation of wells and plumes of the Novo-Chaselskoye field G = 0.933 kg /1000 m^3.

The decrease in temperature at which hydrate formation begins to occur is explained by the presence of dissolved salts in the water. In light of this, it is necessary to take into account this factor when water is mineralized in excess of 30 to 40 mg/l. In the carried-out reservoir water of Cenomanian deposits at the Novo-Chaselskoye field, the salinity index of the solution is no more than 20 mg/l [11].

This value of the mineralization of the solution affects the freezing point, namely, its decrease.

The result of the event is presented in Table 3.

Table 3. Results of the design of measures to prevent the formation of hydrates.

Parameter	The value is up to	The value after	Change
Hydrate formation temperature,°C	11.5204	1	-10.5204
Inter-repair period, day	654	1020	366
Seasonal consumption of methanol, t: - the cold season - the warm season	 0 0	 933 50	 933 50
Gas production by wells of bush No.288, million m^3	8265.2	12342.1	4076.9

4 Conclusion

Based on the above, we can conclude that the temperature of mineralized water at the end of the plume and the freezing temperature of an aqueous methanol solution contribute to the determination of the value of the parameter ΔT [13]. For the greatest accuracy in accounting for mineralization, it is necessary to lower the value of ΔT by several tenths of a degree. This is due to the fact that the mineralization of the aqueous phase at the end of the plume is less than the mineralization of reservoir water.

Considering the Cenomanian deposits and deposits of Western Siberia, it is worth noting that there is no need to take into account the mineralization of the aqueous phase at the end of the plume. A sufficient measure would be to create a small excess of methanol concentration, ranging from 15% to 20%. However, if we turn to situations in deposits with a high level of mineralization of reservoir waters, the scheme for calculating the consumption of methanol to prevent ice and hydrate formation radically changes. Thus, as a result of metered injection of methanol in the wells of bush No. 288 of the Novo-Chaselskoye field, the following effects were achieved: a decrease in the temperature of hydrate formation by -10.5204 ° C, an increase in the inter-repair period from 654 days to 1020 days, while an increase in gas production by 4076.9 million m^3.

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