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Research paper

Wells Gas Hydrates Formation Analysis and Prevention Methods

Anna Liashenko[1]*, Oleksandr Melnikov[2], Ruslan Petrash[3], Oleksandr Petrash[4]

[1] *Poltava National Technical Yuri Kondratyuk University, Ukraine*
[2] *Poltava National Technical Yuri Kondratyuk University, Ukraine*
[3] *Poltava National Technical Yuri Kondratyuk University, Ukraine*
[4] *Poltava National Technical Yuri Kondratyuk University, Ukraine*
**Corresponding author E-mail: anliashenko14@gmail.com*

Abstract

The article deals with laws of occurrence of gas hydrates in mining wells and prevention of their formation. The basic calculations for determining temperature regimes in wells have been described. The basic methods of struggle against hydrated deposits in wells have been demonstrated. The detailed description of hydrates occurrence causes is presented along with methods of its prevention from a technological perspective. This paper provides data on the techniques used for production string clearing from hydrate plagues. The conditions necessary for hydrates formations are presented. The technological methods of hydrates removal from a tubing have been described.

Keywords: *gas-hydrated deposits, inhibitor, production well, throttling, well operation mode*

1. Introduction

Many components of natural gas (methane, ethane, propane, isobutane, carbon dioxide, nitrogen, hydrogen sulfide) in combination with water form gas hydrates – solid crystalline compounds that exist at high pressures at temperatures above 0 ° C.

During gas production, hydrates can form in field communications and wellbores. When laying off on the pipe walls (especially in the locations of fittings, valves, turns, etc.), hydrates drastically reduce their throughput, up to the complete cessation of gas flow [3, 5-7].

Currently, there is an extensive literature describing the composition, structure, and physicochemical properties of the hydrates of individual components of natural gases and their mixtures, thermodynamic conditions for the existence of hydrates, and methods for preventing and eliminating hydrate plugs in wells and gas pipelines. In particular, a significant amount of studies on the described problems was performed by Hammerschmidt, Carson, Katz, Kobayashi, McKetta, Wilcox., Deaton, Frost, Robinson, Huston, Lacroix, Connealy and others.

Hydrates are non-stoichiometric compounds-inclusions of variable composition, and the equilibrium conditions of their existence (i.e. temperature and pressure) are strongly influenced by the composition of the gas, as well as the presence of salts and other antifreezes in water (received the name of hydrate formation inhibitors in gas practice), reducing both the freezing point of water and the equilibrium temperature of hydrate formation.

It is necessary to know with sufficient accuracy the temperature of the onset of hydrate formation for gas from each investigated area in the operating pressure range for successful testing, development, and operation of gas wells, and in order to select and calculate the amount of hydrate formation inhibitor.

Engineering practice utilizes a relative specific gravity of a gas for approximate calculations of hydrates depositions. It requires a nomogram proposed by D.L. Katz [15]. This method is very simple and convenient for practical use. However, since gases of different composition may have the same specific weight, this characteristic is not sufficiently defined. Khoroshilov [16] introduced into the engineering practice more accurate, and more time-consuming method for determining hydrate formation conditions by the calculation of equilibrium constants.

Gas field systems, in which the formation of technogenic gas hydrates is possible, include: well bottom zone, borehole; loops and collectors; gas treatment facilities; main sections of gas pipelines; gas distribution stations; field and trunk pipelines; gas treatment and processing plants.

2. Main Body

A number of methods have been developed in order to prevent hydrates, the ones using chemical reagents are shown in Figure 1. They include hydrate formation inhibitors [6, 7, 16, 17].

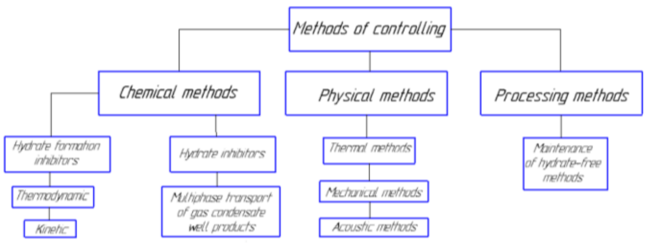

Fig. 1: Methods of dealing with technogenic hydrate formation in the gas field and gas transportation systems

The formation of hydrates in wells and field gas pipelines and the prevention method choice mostly depends on the formation temperature, climatic conditions, and the well operation regime.
A specific application of various methods of preventing hydrate formation is shown below. Prevention and elimination of gas hydrates in various gas field systems is among them.
There are conditions for the hydrates formation in the wellbore, when the temperature of the gas, as it moves up from the bottom to the head, becomes lower than the temperature of hydrate formation [1, 2].
The well becomes clogged with hydrates as a result. It is preferable to determine the temperature change in the operating well using deep-well instruments. If this is not possible, the following formula is applied:

$$t=t_{lim}-\Delta t_i e^{-\alpha(H-1)}+\{(1-e^{-\alpha(H-1)})(G-(D_i(p_c-p_u)/H)-(A/c_p))/\alpha\} \quad (1)$$

where t, t_{lim} are the temperatures of the stream and soil at the depth of l respectively;

$$t_{lim}= t_{res}-G(H-1) \quad (2)$$

where t_{res} is a reservoir temperature at depth of H; G is geothermal gradient value at the interval, Δt_i is temperature change in the bottomhole zone due to the Joule-Thomson effect, °C.

$$t_i=Di(p_{res}-p_c)\{lg(1+(Gc_p\tau/\pi hc_p r_c^2))\}/lg(r_k/r_c) \quad (3)$$

Equation (3) can be simplified to

$$t_i=Di(p_{res}-p_c) \quad (4)$$

where r_k is the drainage radious of a well, m; r_c is the well radius, m; Di is the Joule-Thomson differential coefficient, °C/MPa; $p_{пл}$ is the reservoir pressure, MPa; p_c is the bottom hole pressure in the well, MPa, G is the mass consumption of gas; C_p is gas heat capacity at constant pressure; τ is the well production period, s; h is the reservoir height (completion interval), m; $c_п$ is the formation heat capacity, J/m^3.

$$a=\frac{2\pi\lambda_n}{Gc_p f(\tau)} \quad (5)$$

where λn is the formation thermal conductivity, J/m·s·deg; f(τ) is a dimensionless function.

$$f(\tau)=\ln\left(1+\sqrt{\pi\lambda_n / c_n r_c^2}\right) \quad (6)$$

The magnitude of the geothermal gradient depends on many variables; it should be calculated according to temperature measurements in wells that have been idle for a long time. The gas temperature in the plugs can be calculated by the Shukhov formula, valid for small pressure drops.

$$t_l = t_{cp} + \left(t_0 - t_{cp}\right)e^{-k\pi D/Gc_n} \quad (7)$$

where t_l is the flow temperature in °C at a distance of l from the start of the loop; t_{cp} is temperature of the environment in which the loop is laid in °C; t_o is gas temperature at the beginning of the loop, °C; D is the internal diameter of the loop; K is the heat transfer coefficient, J/m·s.
The collector is calculated using the same formula. Due to the decrease in the temperature of the gas as it moves along the wellbore, there is always condensation water in the flow. Therefore, the formation of hydrates is due only to the ratio of pressure and temperature.

According to the graph shown in Figure 2, you can determine the place of formation of hydrates in the wells. Similarly, it is possible to establish the places of their formation in the loops and collectors with the only difference that there it is necessary to select areas where the gas temperature is below the dew point, i.e. where is droplet water.
The values required for calculations using formulas are taken from reference books of thermal physical values.
The formation of hydrates in the wellbore can be prevented by thermal insulation of flowing or casing strings, by raising the temperature of the gas in the barrel by using heaters. The most common way to prevent the formation of hydrates is to feed inhibitors (methanol, glycols) into the gas stream. Sometimes the inhibitor feeds through the annulus. The choice of reagent depends on many factors.

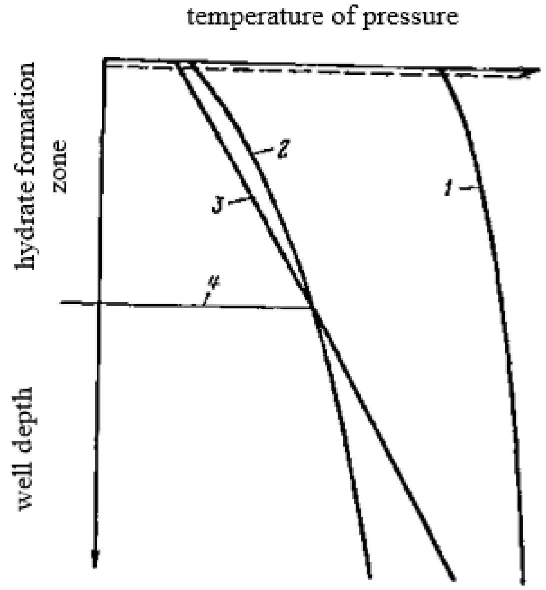

Fig. 2: Determination of the zone of possible formation of hydrates, where 1 is a well pressure; 2 is equilibrium temperature of hydrate formation; 3 is temperature in the well; 4 is the depth of the neutral layer

It should be noted that there is such a flow rate, above and below which the temperature of the gas at the mouth does not rise, but decreases. This is explained by the fact that at low flow rates the gas temperature at the mouth mainly depends on the heat exchange of gas with the walls of the well, and at high flow rates due to an increase in their friction losses, the Joule-Thompson effect begins to prevail over the heat transfer effect.
The place of the beginning of hydrate formation in wells is determined by the point of intersection of the equilibrium hydrate formation curve with the gas temperature variation curve along the wellbore (Figure 3).

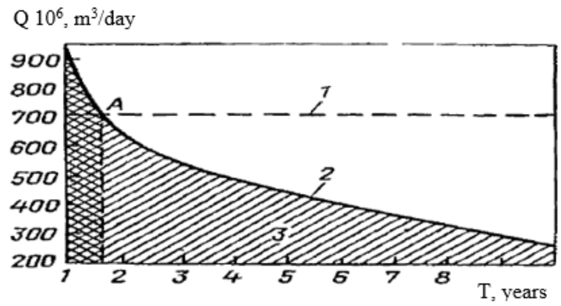

Fig. 3: The change in the allowable flow rate, which prevents the formation of hydrates, in the process of field development: 1 is the allowable flow rates line; 2 is the project flow rate; 3 is the hydrates zone

In practice, the formation of hydrates in the wellbore can be prevented by reducing the working pressure at the wellhead and reducing the gas flow rate. If the hydrates do not completely cover the well cross-section, it is the easiest to achieve its decomposition by utilizing inhibitors. It is much more difficult to deal with hydrate deposits that completely overlap the cross section of the production string and form a continuous hydrate plug. With a small length of the tube, its elimination is usually carried out by blowing a well. With a considerable length, a plug is ejected into the atmosphere before a certain period during which it partially decomposes as a result of a pressure decrease. The duration of the hydrates decomposition period of depends on the length of the plug, the gas temperature and the composition of rocks. Solid particles (sand, sludge, scale, mud particles, etc.) slow down the decomposition of the plug. To accelerate this process, inhibitors are used [4, 8, 9, 11].

It should also be taken into account that when a hydrate plug is formed in the zone of negative temperatures, the effect is obtained only with a decrease in pressure. The fact is that the water released during the decomposition of hydrates at a low inhibitor concentration may freeze and an ice plug forms instead of a hydrate one, which is difficult to eliminate.

If a long plug is formed in the wellbore, it can be eliminated by applying the closed circulation of the inhibitor over the plug. As a result, mechanical impurities are washed out, and an inhibitor of high concentration is constantly contained on the surface of the hydrate plug [12, 14].

The formation of hydrates in the wellbore is observed in both gas and oil wells and is characteristic of the development and exploration of wells, and during the start-up and shut-in periods for technological reasons.

To prevent the formation of hydrates in the wellbores, traditional methods are used, they are maintenance of hydrate-free modes, prevention of hydrate deposits and the flow of inhibitor to the bottom of the well.

The place of formation of the hydrate plug is usually determined by the increase in pressure drop in a given section of the pipeline. If the plug is not solid, then an inhibitor is introduced into the pipeline through special connections, fittings for pressure gauges or through a purge plug. If solid hydrate plugs of small length were formed in the pipeline, they can sometimes be eliminated in the same way.

With a cork length of hundreds of meters, several windows are cut out in the pipe above the hydrate plug and methanol is poured through them. Then the pipe is welded again [16, 17].

A combined method is used for a rapid decomposition of the hydrate plug: the pressure is being reduced simultaneously with the introduction of the inhibitor in the zone of hydrate formation [5, 6].

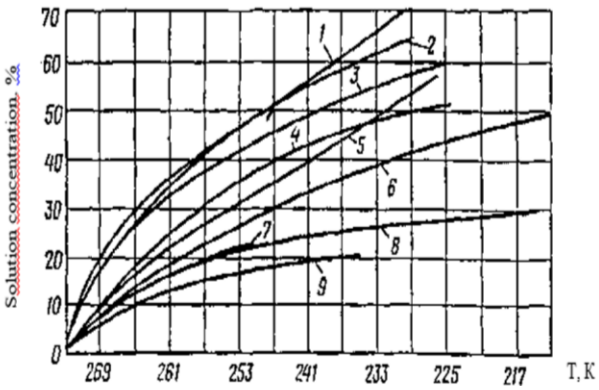

Fig. 4: The dependence of the freezing point of water on the concentration of the solution. Inhibitors: 1 - glycerin; 2 - TEG; 3 - DEG, 4 - EG; 5 - C_2H_5OH; 7 - NaCI; 8 - CaC12; 9 - $MgCl_2$

To prevent the formation of hydrates in the wellbores, traditional methods are used: maintenance of hydrate-free modes, prevention of hydrate deposits and the flow of inhibitor to the bottom of the well.

Maintenance of hydrate-free (idle) modes of wells is achieved by selecting the appropriate working well rates, providing the temperature at the mouth above the equilibrium temperature of hydrate formation. It is possible to increase the temperature of the gas at the wellhead by partially throttling the gas at the bottom of the well, using heat-insulated casing or lift pipes, etc.

The formation of hydrates when setting a well into operation may be considered as a continuation of the formation of a plug that appeared during the shut-in period. If the phase redistribution in the tubing did not complete and the hydrate deposits did not completely block the cross-section of the lift pipes, then, when starting the gas-lift gas contacts the cooled water and forms hydrates, which, in combination with the hydration phase, quickly form a stable plug. Therefore, in the initial period, the well is working but then the flow of oil and gas decreases gradually [12].

Hydrates are most intensely formed during the operation of wells after drilling and workover. This is due to the fact that the bottom hole zone is saturated with water that has infiltrated formation from the drilling mud. During development, it is carried by the reservoir fluid into the well. It enters the hydrate phase after the contact with a gas.

An additional factor causing a decrease in the flow temperature is gas throttling through a leak in the threaded connections of the lift pipes. Calculations show that the pressure drop in the annulus and the inner part of the tubing in the zone of possible hydrate formation reaches 2.0 ... 6.0 MPa. Leakage of the tubing can also lead to the cooling of the gas-liquid flow and accelerate the formation of hydrates.

Depressurization of the tubing is also cause by a method of removing deposits - scraping. Since the sediments are mechanically removed in the process of scraping and due to a curvature of the wellbore, the inner surfaces of the pipes experience various forces from the scraper and the protective film that is formed during operation is being removed at spots of intense stress. When it coincides with the coupling area, the process of depressurization of threaded connections is enhanced due to the removal of the protective film, [13]. To reduce the effect of this factor, periodical washing with solvents, which contribute to the restoration of protective films, is used along with scraping.

Due to paraffin deposits, oil degassing is also accelerated, additional gas-liquid flow is cooled, especially in the permafrost zone, which intensifies the process of hydrate formation.

Gas dehydration to the dew point (eliminating moisture loss in the condensed phase – drip moisture or hydrates) is used during preparation of a gas for a long-distance transportation through main gas pipelines. However, it’s not applicable to prevent hydrate formation in wellbores and field communications [3, 5, 6, 11, 13, 16].

3. Conclusions

Thus, the formation of hydrates during oil production contributes to low reservoir temperature, the presence of zones with reduced temperature or high gas factor in the section, paraffin sediments, well shutdown, low production rate with good production well characteristics, and leakage of the tubing [1, 2, 10].

The formation of hydrates in the tubing can be prevented by thermal insulation of flowing or casing strings, by raising the temperature of the gas in the barrel using heaters. The most common way to prevent the formation of hydrates is to feed inhibitors (methanol, glycols) into the gas stream, and also change the mode of operation of the well.

Analysis of the factors determining the conditions of hydrate formation shows that to prevent the formation of hydrates in the gas stream and eliminate existing hydrate plugs, it is possible to lower the pressure and increase the temperature of the gas, to make it dry, and also to change the equilibrium conditions of the gas-hydrate-water system by introducing antihydrate inhibitors .

All these methods are widely used in the gas industry, however, the scope of each of them is characterized by the specific conditions of the technological process of gas production, collection, field processing and transportation.

Thus, a decrease in pressure below the onset of hydrate formation in wellbores, stubs and gas pipelines is usually possible only when gas is released into the atmosphere. Thus, this is an emergency method, which is applicable on a limited scale only to eliminate the already formed hydrate plugs.
Increasing the temperature of the gas by heating, insulating the pipelines and (or) maintaining optimal high-temperature conditions it used to prevent the formation of hydrates in wells and loops, but is practically inapplicable during long-distance gas transportation through main pipelines.
A more universal method, widely used both to prevent the formation of hydrates and to decompose already formed hydrate plugs, is to introduce various hydrate formation inhibitors, such as methanol, glycols, electrolyte solutions, which shift the equilibrium parameters of hydrate formation to lower temperatures, into the gas stream.
Thus, inhibitors and various ways to keep the gas temperature above the equilibrium temperature of hydrate formation are most widely used to avoid the hydrates in wells and gas gathering loops.

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