MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

СӘТБАЕВ УНИВЕРСИТЕТІ | SATBAYEV UNIVERSITY

School of geology, petroleum and mining engineering
Department of Petroleum Engineering

Muratova Z. M.

Formation of hydrates during the transportation of natural gases and methods of control

**DIPLOMA WORK**

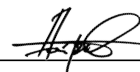5B070800 – Oil and gas engineering

Almaty 2021

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KAZAKHSTAN

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School of geology, petroleum and mining engineering
Department of Petroleum Engineering

**APPROVED FOR DEFENSE**

Head of the Petroleum

Engineering Department

Dairov Zh. K., MSc

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**DIPLOMA WORK**

Topic: «Formation of hydrates during the transportation of natural gases and methods of control»

5B070800 – Oil and gas engineering

Performed by                                                                                    Muratova Z.

Academic adviser

Doctor of Chemical
Sciences

Professor Selenova B.S.

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Almaty 2021

## Метаданные

Название
**Formation of hydrates during the transportation of natural gases and methods of control**

Автор
**Муратова Зарина**

Научный руководитель
**Багдат Селенова**

Подразделение
**ИГНиГД**

## Список возможных попыток манипуляций с текстом

В этом разделе вы найдете информацию, касающуюся манипуляций в тексте, с целью изменить результаты проверки. Для того, кто оценивает работу на бумажном носителе или в электронном формате, манипуляции могут быть невидимы (может быть также целенаправленное вписывание ошибок). Следует оценить, являются ли изменения преднамеренными или нет.

| Замена букв | ß | 10 |
|---|---|---|
| Интервалы | A→ | 0 |
| Микропробелы | | 2 |
| Белые знаки | ß | 0 |
| Парафразы (SmartMarks) | a | 0 |

## Объем найденных подобий

Обратите внимание!Высокие значения коэффициентов не означают плагиат. Отчет должен быть проанализирован экспертом.

| 0.14% 0.14% КП1 | 0.00% 0.00% КП2 | 0.41% 0.41% КЦ |
|---|---|---|
| **25** Длина фразы для коэффициента подобия 2 | **7274** Количество слов | **45095** Количество символов |

## Подобия по списку источников

Просмотрите список и проанализируйте, в особенности, те фрагменты, которые превышают КП №2 (выделенные жирным шрифтом). Используйте ссылку «Обозначить фрагмент» и обратите внимание на то, являются ли выделенные фрагменты повторяющимися короткими фразами, разбросанными в документе (совпадающие сходства), многочисленными короткими фразами расположенные рядом друг с другом (парафразирование) или обширными фрагментами без указания источника ("криптоцитаты").

### 10 самых длинных фраз

Цвет текста

| ПОРЯДКОВЫЙ НОМЕР | НАЗВАНИЕ И АДРЕС ИСТОЧНИКА URL (НАЗВАНИЕ БАЗЫ) | КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ) | |
|---|---|---|---|
| 1 | **The trade war between the US and China.docx** Ғани Әшімов 5/12/2020 University of Foreign Languages and Professional Languages (deanary ) | 10 | 0.14 % |

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### из домашней базы данных (0.00 %)

| ПОРЯДКОВЫЙ НОМЕР | НАЗВАНИЕ | КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ) |
|---|---|---|

## из программы обмена базами данных (0.14 %) ■

| ПОРЯДКОВЫЙ НОМЕР | НАЗВАНИЕ | КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ) | |
|---|---|---|---|
| 1 | **The trade war between the US and China.docx**<br>Ғани Әшімов **5/12/2020**<br>University of Foreign Languages and Professional Languages (deanary ) | 10 (1) | 0.14 % |

## из интернета (0.00 %) ■

| ПОРЯДКОВЫЙ НОМЕР | ИСТОЧНИК URL | КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ) |
|---|---|---|

## Список принятых фрагментов (нет принятых фрагментов)

| ПОРЯДКОВЫЙ НОМЕР | СОДЕРЖАНИЕ | КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ) |
|---|---|---|

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Department of Petroleum Engineering

**CONFIRM**

Head of the Petroleum

Engineering Department

Dairov Zh. K., MSc

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**TASK**

**For completing the diploma work**

For student Muratova Z.

Topic: «Formation of hydrates during the transportation of natural gases and methods of control»

Approved by the order of university rector № 2131-b from 24.11.2020

Deadline for completion the work 18.05.2021

Initial data for the diploma work: total gas injection, dosage of the reagent, reagent consumption, gas pressure at the manifold and at the compressor outlet.

Summary of the diploma work: The analysis will be based on the results of three pilot tests carried out at the X field.

The list of issues to be developed in the diploma work:

a) Consider general methods of combating hydrate formation;

b) Choose an effective method for the prevention of hydrates in the X field;

c) Economically and technologically justify the chosen method for combating hydrate formation.

Recommended main literature:

1. D. Sloan, C. Koh, A. Sum, A. Ballard, J. Creek, M. Eaton, J. Lachance, N. Mcmullen, T. Palermo, G. Shoup and L. Talley, Natural Gas Hydrates in Flow Assurance - 1.3 Four Rules of Thumb Arising fromCrystal Structure. (pp. 2,3,4), Elsevier, 2011.

2. Aksyutin O.E., Menshikov S.N., Laperdin A.N. and others. Conditions of formation and methods of combating hydrates in the gas field of the Yamsoveyskoye field: Review of inform. - M.: Gazprom expo, 2010.88 p. (Geology, drilling, development and operation of gas and gas condensate fields).
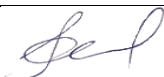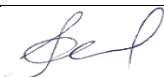
## SCHEDULE

for the diploma work preparation

| Name of sections, list of issues being developed | Submission deadline to the Academic adviser | Notes |
|---|---|---|
| Introduction, theoretical part | 10.02.2021 | Task completed |
| Technological part | 15.03.2021 | Task completed |
| Results and discussion | 31.03.2021 | Task completed |
| Conclusion | 16.04.2021 | Task completed |

## SIGNATURES

Of consultants and standard controller for the completed diploma work, indicating the relevant sections of the work.

| The section titles | Consultant name (academic degree, title) | Date | Signature |
|---|---|---|---|
| Introduction, theoretical part | Doctor of Chemical Sciences, Professor Selenova B.S. | 10.02.2021 | |
| Technological part | Doctor of Chemical Sciences, Professor Selenova B.S. | 15.03.2021 | |
| Results and discussion | Doctor of Chemical Sciences, Professor Selenova B.S. | 31.03.2021 | |
| Norm control | Doctor of Chemical Sciences, Professor Selenova B.S. | 16.04.2021 | |

Academic Adviser                                                                       Selenova B.S.
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The task was accepted by student:                                          Muratova Z.
_____

Date                                                                                   «18» May 2021

# АННОТАЦИЯ

В данной дипломной работе выполняется анализ борьбы с образованием гидратов при транспортировке природных газов на месторождении Х.

Цель дипломной работы: подбор эффективного метода для предотвращения образования гидратов при транспортировке природных газов на месторождении Х. Для выполнения задачи предложены следующие шаги:

1.     Рассмотреть общие методы борьбы с гидратообразованием;

2.     Подобрать эффективный метод для предупреждения образования гидратов на месторождении Х;

3.     Экономически и технологически обосновать выбранный метод для борьбы с гидратообразованием.

Объект исследования: системы транспортировки газа на месторождении Х.

Актуальность работы заключается в том, что месторождение Х расположено в области, способствующей образованию гидратов.

# АННОТАЦИЯ

Бұл дипломдық жұмыста X кен орнында табиғи газдарды тасымалдау кезінде гидраттардың пайда болуымен күреске талдау жасалады.

Дипломдық жұмыстың мақсаты: X кен орнында табиғи газдарды тасымалдау кезінде гидраттардың пайда болуын болдырмаудың тиімді әдісін таңдау. тапсырманы орындау үшін келесі қадамдар ұсынылады:

1. Гидраттың пайда болуымен күресудің жалпы әдістерін қарастырыңыз;

2. X кен орнындағы гидраттардың алдын алу және жою үшін тиімді әдістемені таңдау;

3. Гидраттың пайда болуымен күресудің таңдалған әдісін экономикалық және технологиялық тұрғыдан негіздеу.

Зерттеу нысаны: кен орнындағы газды тасымалдау жүйесі X.

Жұмыстың өзектілігі X кен орны гидраттардың пайда болуына ықпал ететін аймақта орналасқандығында.

# ABSTRACT

In this diploma work, the analysis of the fight against the formation of hydrates during the transportation of natural gases at the X field.

The purpose of the diploma work: the selection of an effective method for preventing the formation of hydrates during the transportation of natural gases in the field X. To complete the task, the following steps are proposed:

1.      Consider general methods of combating hydrate formation;

2.      Choose an effective method for the prevention of hydrates in the X field;

3.      Economically and technologically justify the chosen method for combating hydrate formation.

Object of research: gas transportation systems at field X.

The relevance of the work lies in the fact that the X field is located in an area that promotes the formation of hydrates.

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# INTRODUCTION

The processes of gas production, transportation, storage and processing are involved in the formation of gas hydrates. This problem is due to the presence in the gas stream of an aqueous phase capable of forming composites and gas molecules at a given temperature and pressure in the pipeline. This process can affect the physical and chemical properties of water and gas. The formation of hydrate deposits in the discharge zone under the reservoir affects the flow rate of the well, i.e. it decreases. Particular attention is paid to the preparation of gas vehicles on the main gas pipeline, as well as in areas with high average flow rates. Hydrate formation partially or completely impedes the flow of the pipe, resulting in high pressure zones in the pipe. By pushing the cap of hydrogenated gas into the gas distribution station, it is possible to create conditions for dynamic gas shock, which is one of the mechanisms of rapid rupture of the pipe.

Conventional hydrates cause serious difficulties in the operation of gas fields and even major accidents. Currently, the prevention of these complications is a scientific, technical and industrial issue. To date, the conditions of formation and degradation of hydrate compounds have been studied in detail. The values of temperature and pressure can be explained by the probability of hydrate formation. Various models of hydration formation mechanisms are proposed, hydration flow rates under different conditions are studied, factors influencing hydration formation rate, methods of temperature and pressure calculation in gases, liquids and gas-liquid mixtures in pipes are determined, as hydrated growth rates develop. The basis of a method of struggle against formation of hydrates which can be used under certain conditions is stated. The costs of oil and gas companies to prevent and control hydrated gas congestion are an important part of field operations and transportation costs for gas. Therefore, many mining companies in the oil and gas industry prefer to prevent the formation of hydrates in field gas production systems and reduce management costs for further gas transportation.

# 1 General information about the X field

## 1.1 Location of field X

The X deposit is administratively located in the Beineu district of the Mangistau region of the Republic of Kazakhstan. The work area is located in the southeastern side zone of the Caspian Basin.

The nearest settlement to the deposits is the regional center Beineu. The regional center - Aktau - is located 530 km southwest of the fields. The nearest railway station is St. Supporting. The close proximity to the well-equipped oil fields Prorva, Tengiz, Kisimbai, as well as to the railway line creates favorable conditions for the development of deposits.

The relief of the area is calm, a slight increase in heights occurs from south to north and southwest to northeast.

The climate of the region is sharply continental and is characterized by significant fluctuations in seasonal temperatures. In the winter season, the air temperature drops to minus 25˚C – minus 40˚C, in the summer, the temperature ranges from + 25˚C to + 50˚C. The amount of annual precipitation does not exceed 150 mm per year and mainly falls in the autumn-winter period. The winds are predominantly southeast and northwest, the wind speed is from 5 to 15 m/s.

## 1.2 Natural and climatic conditions

The climate of the region is sharply continental and arid. It is characterized by a cold winter with a stable snow cover and a relatively short, moderate hot summer, large annual and daily fluctuations in air temperature, late spring and early autumn frosts, constantly blowing winds.

In orographic terms, the area of work is a hilly desert area, covered in places with unfixed dune sands up to 3 m high. Absolute marks on the area vary within 20-25 m.

According to the "Center for Hydrometeorological Monitoring" of the RSE "Kazhydromet", climatic characteristics for the area of field X in the Beineu district of the Mangistau region are presented in tables 1 - 4 according to the observations at the nearest meteorological station Beineu for the period from 1986 to 2010.

**Table 1.2.1 - Average monthly and average annual air temperature (degrees ˚C)**

| I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -6,1 | -5,4 | 1,8 | 12,2 | 19,1 | 25,7 | 28,0 | 26,7 | 19,1 | 10,5 | 1,7 | -4,1 | 10,8 |

**Table 1.2.2 - Average monthly and average annual precipitation, mm**

| I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Year |
|---|----|-----|-----|-----|-----|-----|------|-----|-----|------|------|------|
| 8,9 | 9,0 | 8,5 | 12,1 | 20,2 | 18,2 | 15,5 | 2,4 | 6,9 | 9,1 | 11,7 | 10,3 | 132,8 |

**Table 1.2.3 - Average monthly and average annual wind speeds, m/s**

| I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Year |
|---|----|-----|-----|-----|-----|-----|------|-----|-----|------|------|------|
| 3,4 | 3,5 | 3,7 | 3,6 | 3,0 | 2,7 | 2,4 | 2,4 | 2,8 | 3,0 | 3,1 | 3,2 | 3,1 |

**Table 1.2.4 - Average annual frequency (%) of wind and calm directions**

| N | NE | E | SE | S | SW | W | NW | Wind |
|---|----|----|----|----|----|----|----|------|
| 5 | 5 | 19 | 22 | 11 | 6 | 16 | 16 | 27 |
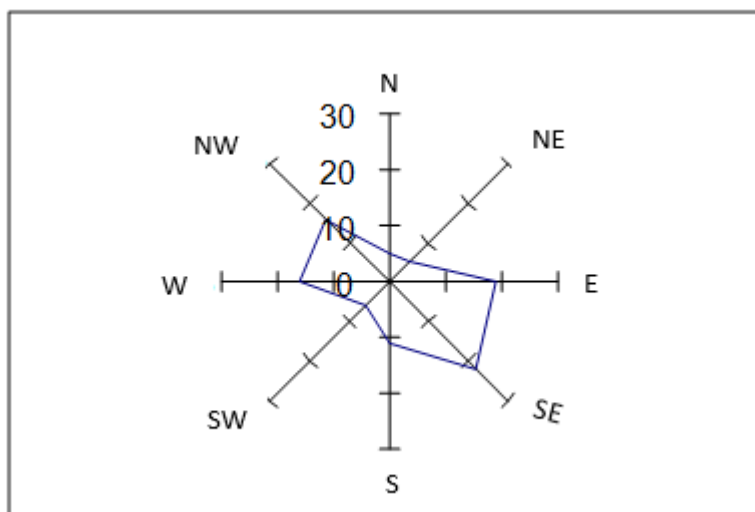


**Figure 1.2.1 - Wind rose for 2010 in Beineu region**

## 1.3   Thermobaric characteristic

For the Jurassic aquatic complex is characterized by a great formation temperature of 88-91 ˚C. Values of reservoir pressures vary from 35.3 to 38 MPa.

For the Triassic aquifer complex, the formation layer temperature reaches 112 ˚C, the formation pressure - 46.8 MPa.

According to the Figure 2, the thermogradient and the vertical gradient of the formation pressure are calculated. The magnitude of the thermogradient is quite significant and is 3.2 ˚C/100 m, the value of the geothermal step is 31.25 m/s. The vertical gradient of the formation pressure is equal to 0.011 MPa/m or 1.1 MPa/100 m, which is typical for infiltration systems.
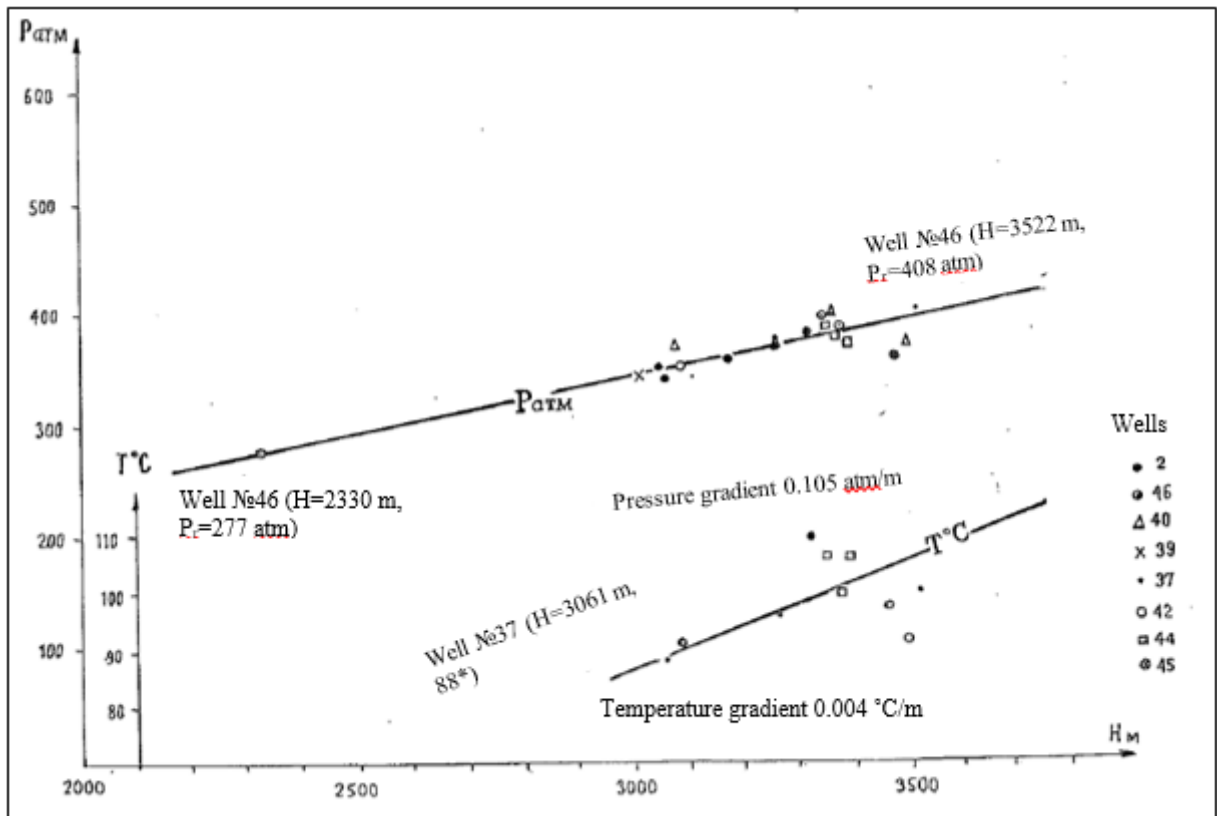
**Figure 1.3.1 - Schedule of changes in formation pressure from the depths at the X field**

## 2    Theoretical part

When transporting natural gas, the essential main task is to prevent the formation of hydrates during operation. In many underground pipelines, the soil temperature is close to 0 °C. It provides ideal conditions for compressed hydrocarbon gas and water to form hydrates, these hydrate plugs resemble snow or ice. Deeper depth increases the higher working pressure in the production lines.

Hydrates clog equipment and pose a safety hazard, creating plugs that look like snow or ice. Based on the above, it is necessary to understand where clogging of any type of hydrates is possible. The main task that is performed in the flow support area is to set a" no contact time " (NCT) for the field. NCT is the time when liquids can stop on production lines until the hydrate is formed and the system is safely restarted. The temperature of the production lines to reach the temperature at which the hydrate is formed during the working pressure in the production lines is called the "cool down" period. The quantitative difference between the temperature of hydrate formation and the actual temperature of liquids in the pipeline is called "sub cooling". If the system remains stable during a long cooling period and outside the NCT, it usually requires depressurization (for hydrate dissociation) or circulation of hot liquids, which can take a long time. [1]

### 2.1    General characteristics of natural gas hydrates

Natural gas, saturated with water vapor at high pressure and a certain positive temperature, forms solid compounds with water, called hydrates.

The formation of hydrates is a problem in the development of fields with low reservoir temperatures and harsh climatic conditions, which create favorable conditions for the formation of hydrates not only in wells and gas pipelines, but also in reservoirs, which leads to the formation of deposits of gas hydrates.

Natural gas hydrates are unstable physicochemical compounds of water with hydrocarbons that decompose into gas and water when the temperature rises or the pressure drops. Outwardly, they resemble snow or ice.

Hydrates are clathrate compounds because the lattice structure is formed by gas molecules containing water molecules. The three most common hydrates are SI, SII and SH. [1]

In Figure 2.1.1 shows the shape of these structures. [1]
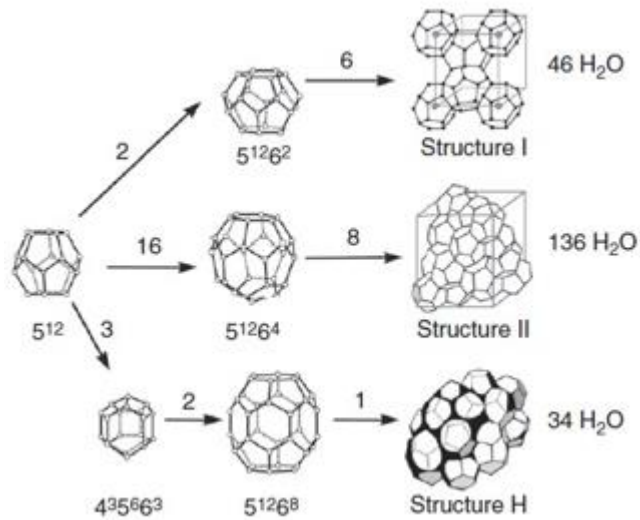
**Figure 2.1.1 – Exemplification of the three main hydrate unit crystals (SI, SII. SH) and their composite cells**

The oil and gas industry often faces problems related to the structures of SII hydrates. [1]

Hydrates resemble snow or ice. Figure 2.1.2 shows two cases, how hydrate is represented. In the first case, the hydrate is similar to snow, the same loose, porous and less dense, while in the second case, the hydrate formed into a cork similar to ice, very strong, with little porosity and much denser. [2]



**Figure 2.1.2 – Physical characteristics of hydrates**

## 2.2 Conditions of hydrate formation

The formation of a hydrate requires the following three conditions:

1. Favorable thermobaric conditions. The formation of hydrates is favored by a combination of low temperature and high pressure;

2. The presence of a hydrate-forming substance (methane, ethane, carbon dioxide);

3. Adequate amount of water. There should not be too much water, or too little.

To prevent hydrate formation, it is sufficient to exclude one of the three conditions listed above. We cannot remove the hydrate-forming substance from the mixture, since it is the hydrate-forming substances in natural gas that are the useful product. [3]

## 2.3    Effective methods to prevent and eliminate the formation of hydrates during the transportation of natural gases

To prevent the formation of hydrates, it is necessary to exclude one of the basic conditions for the existence of hydrates: high pressure, low temperature, or free humidity of the gas. Accordingly, the prevention of hydrate formation is carried out by introducing inhibitors into the gas stream, drying the gas from water vapor, maintaining the gas temperature above the hydrate formation temperature and maintaining the pressure below the hydrate formation pressure.

### 2.3.1  Elimination of hydrates by pressure reduction

The pressure reduction method is widely used to remove the formed hydrates in the wellbore, in field and main gas pipelines, where the temperature as a result of hydrate decomposition does not drop below 0˚C. For this, the section of the gas pipeline on which the hydrates have formed is turned off, and gas is released into the atmosphere through the purge plugs. Decay products are blown out through one of the candles. After that, the section is put into operation again. This procedure can also be carried out by a one-way discharge of gas from a gas pipeline. [3]

### 2.3.2  Elimination of hydrates by heating

The heating method is used on short gas pipelines to decompose already formed hydrates or to prevent the formation of hydrates in places of gas depletion. The gas is heated in the heat points by open fire, steam, water or other heat carriers. [3]

### 2.3.3  Inhibitor injection

The most effective method of preventing hydrate deposits is the method of introducing inhibitors into the gas flow. In practice, electrolytes, alcohols and glycols are often used as inhibitors. By dissolving in gas-containing water, inhibitors reduce the pressure of water vapor. In addition, if hydrates are formed, then at a low temperature. The introduction of inhibitors with already formed hydrates reduces the water vapor pressure and alters the balance in the hydrate - water system. The plasticity of water vapor in hydrates is greater than in aqueous solution, leading to its decomposition. Methanol, calcium chloride, diethylene glycol, etc. are often used as inhibitors. In some cases, combined inhibitors of several substances are also used. This includes a mixture of glycolic methanol and butyl octane. [3]

A hydrate formation inhibitor is a substance that alters the thermobaric conditions of hydrate formation or affects the rate of hydrate formation in a gas-liquid stream.

An increase in the pressure drop in the pipeline section indicates the formation of a hydrate plug. If an intermittent plug or solid plugs of small length are formed, hydrate plugs are eliminated by introducing an inhibitor into the pipeline through special nozzles, pressure gauge fittings, or through a purge plug.

When forming a plug with a length of up to several hundred meters above its place in the pipe, several windows are cut out for the introduction of an inhibitor, after which the pipe is welded again. The combined method is also used for faster decomposition of hydrate plugs.

Basic requirements for inhibitors of hydrate formation:

- Low corrosiveness of hydrate inhibitor;

- Low consumption of inhibitor;

- Low toxicity;

- Compatibility of the inhibitor with formation saline water, produced products (oil/gas/condensate) and with other reagents in the development of multipurpose formulations;

- Possibility and feasibility of regeneration of waste solutions;

- Low freezing point and the ability to use at high reservoir pressures.

Hydrate inhibitors divided into two classes:

1. Thermodynamic inhibitors - substances that change the activity of water and thereby shift the three-phase equilibrium "gas-water phase-gas hydrates" towards lower temperatures. These include aliphatic alcohols, glycols and aqueous solutions of inorganic salts;

2. Kinetic inhibitors - prevent for some time the process of nucleation of hydrates and slow down the growth of viable crystallization centers.

## Table 2.3.3.1 – The types of thermodynamic hydrate inhibitors

| Thermodynamic hydrate inhibitors | Benefits | Disadvantages | Resume |
|---|---|---|---|
| **Aqueous solutions of electrolytes (for economic reasons, an aqueous solution of KCl 25% is used)** | 1.high antihydrate activity;<br><br>2.cheapness of technical grades;<br><br>3.simplicity of solution preparation;<br><br>4.non-toxicity. | 1.very high corrosive activity;<br><br>2.the possibility of sedimentation when mixing with formation saline water; the need for a special unit for the preparation of a working agent. | The use of these inhibitors in the northern regions at large fields seems to be low-tech due to the climatic factor and the peculiarities of the production technology. |
| **Glycol-based antihydrate reagents (the most widely used is diethylene glycol, which is also used as an absorbent in gas drying. Diethylene glycol is an effective inhibitor of hydrate formation)** | 1.low solubility in the gas phase. | 1.high price;<br><br>2.technological difficulties when separating diethylene glycol emulsion with unstable condensate;<br><br>3.high viscosity;<br><br>4.high crystallization temperature, which complicates the use in northern conditions. | In order to reduce the cost of the composition, inhibitors have been developed, consisting of a large number of different glycols, such as polyglycol, ethylene glycol, propylene glycol, etc. Due to the properties of these inhibitors, they are best used in the stages of gas drying and cooling. |
| **Methanol and some compounds based on it. (the use of methanol-based inhibitors is widespread in the fields to prevent hydrate formation and eliminate hydrate deposits)** | 1.relatively low cost and broad industrial base; high manufacturability of the process of introducing and distributing methanol;<br><br>2.the highest antihydrate activity, which remains even at low temperatures; | 1.high toxicity and fire hazard;<br><br>2.possible precipitation of salts when mixed with highly saline formation water;<br><br>3.the effect of accelerated growth of crystalline hydrates in the presence of dilute aqueous solutions of methanol with insufficient | |

| | | |
|---|---|---|
| 3.very low freezing point of methanol solutions and their low viscosity;<br><br>4.relatively low solubility of methanol in unstable condensate;<br><br>5.non-corrosiveness of methanol and its aqueous solutions; the possibility of using technical grades of methanol;<br><br>6.availability of simple technological schemes for the regeneration of waste solutions;<br><br>7.elaboration of the issues of utilization and disposal of industrial effluents containing methanol;<br><br>8.high efficiency of liquidation of discontinuous hydrate plugs. | concentration to prevent hydrates; at insufficient concentration, methanol becomes not an inhibitor, but a catalyst for hydrate formation;<br><br>4.high vapor pressure as well as very high solubility in compressed natural gas. | |

**Table 2.3.3.2 - The types of kinetic inhibitors**

| Kinetic inhibitors | Benefits | Disadvantages |
|---|---|---|
| Water-soluble polymers of low molecular weight (500-1000) with a concentration of 0.5-1 wt. %. | 1.reduction of operating costs;<br><br>2.a higher level of environmental friendliness;<br><br>3.no need to regenerate waste solutions;<br><br>4.the possibility of retrofitting existing methanol injection systems;<br><br>5.reducing the cost of transport and storage of inhibitors. | 1.restrictions on the viscosity of the solution, so the concentration should not exceed 2%;<br><br>2.the freezing point of the solution is close to 0˚C, which also limits the application;<br><br>3.compatibility with formation brine and unstable condensate;<br><br>4.insufficient reliability of the inhibition approach. |

Elimination of hydrates by pressure reduction and heating methods have not found much application in practice, in contrast to the use of inhibitors. Therefore, below we will consider in more detail the chemical methods.

## 3    Technological part

The gas-condensate mixture of the X field has an increased content of hydrogen sulfide and carbon dioxide, which contributes to the formation of hydrate deposits. the formation of hydrates is facilitated by the presence of hydrogen sulfide (up to 1.84 %) and carbon dioxide (up to 2.17%) in the gas composition, which at a pressure of 0.86 MPa and at a temperature of 21.1°C, when combined with water, can form solid crystalline compounds — gas hydrates. Light hydrocarbons, especially methane, account for a high proportion of the component composition. The predominance of methane and its homologues contributes to an increase in the amount of gas condensate in the reservoir. According to the group hydrocarbon composition, the condensate is referred to the methanonaphthenic type with the content of methane hydrocarbons in the boiling fraction up to 300 °C from 53% of the mass. up to 66% of the mass., naphthenic - 27-37% of the mass. and aromatic 4.0-6.5% of the mass.

**Table 3.1 - Component composition of the gas-condensate mixture**

| Component name | Content in the mixture, % mol. |
|---|---|
| Hydrogen sulfide | 1,51-1,84 |
| Carbon dioxide | up to 2,17 |
| Nitrogen | 1,5-1,79 |
| Methane | 73,16-83,3 |
| Ethane | 7,2-7,71 |
| Propane | 2,97-4,59 |
| I-butane | 0,37-0,81 |
| N-butane | 0,50-1,35 |
| I-pentane | 0 |
| H-pentane | 0,12-0,80 |
| Hexane | up to 0,81 |
| Heptane | 0,03-1,07 |
| Octane | up to 1,07 |
| Water | 0,2 |
| C9 and above | 2,62 |

As mentioned earlier, physical and technological methods have not found wide application in practice, in contrast to the use of inhibitors. Therefore, the method of introducing thermodynamic inhibitors was proposed as an effective method for preventing hydrate formation.

In order to confirm the effectiveness of the use of inhibitors in the fight against hydrate formation, 3 pilot tests were carried out at field X using two prototypes (hereinafter reagent №1 and reagent №2).

The purpose of the pilot tests is to confirm the fundamental possibility of using reagents №1 and №2 as inhibitors to ensure uninterrupted fluid transportation.

### 3.1 Pilot test №1 of reagent №1

The tests were carried out from June 27 to July 27, 2010 in the gas utilization department (GUD) and gas compressor unit (GCU).

Brief description of the gas utilization department (GUD) (Figure 3.1.1):

The gas-liquid mixture from satellites 1, 2, 3 at a temperature of 30-40 °C enters a three-phase separator with a volume of 100 $m^3$, where oil, gas and water are separated from each other at a pressure of 6 atm. Oil and water are sent to the oil pumping preparation department (OPPD). The separated gas, leaving the separator, is combined with gas from the oil pumping preparation department (OPPD) and sent to booster compressors 2A and 2B, compressing to 30 atm. Then the gas passes through the droplet separators 11A and 11B, where it is separated from the condensate, and is sent to a 50 $m^3$ gas-liquid separator, separating from the condensate at a pressure of 30 atm. At the same pressure, gas is supplied to the separator inlet from the gas utilization department (GUD). Further, from 50 $m^3$ of the separator, gas goes to booster compressors 3A and 3B, where it is compressed to 140 atm (max.), and through the gas distribution point (GDP) it is injected into wells №401, 404, 405, 406, 415 and 416. A reagent dosing block (RDB) is installed at the outlet of compressors 3A and 3B, where the hydrate inhibitor is pumped on average - 200 kg/day, to prevent the formation of hydrates on the injection line.

Gas from the gas compressor unit (GCU) is injected only into well №401. (Figure 3.1.2) At the outlet of the gas compressor unit (GCU), a mobile dosing unit (MDU) is installed, which doses the inhibitor of hydrate formation on average 50 kg/day. The effectiveness of the inhibitor is determined by the increase/decrease in pressure at the gas distribution point (GDP), which is checked every two hours. The reasons for the pressure increase can be the maintenance work of the equipment carried out during the pilot tests, the volume of produced/injected gas, the injectivity of the wells, insufficient dosage of the reagent, etc.
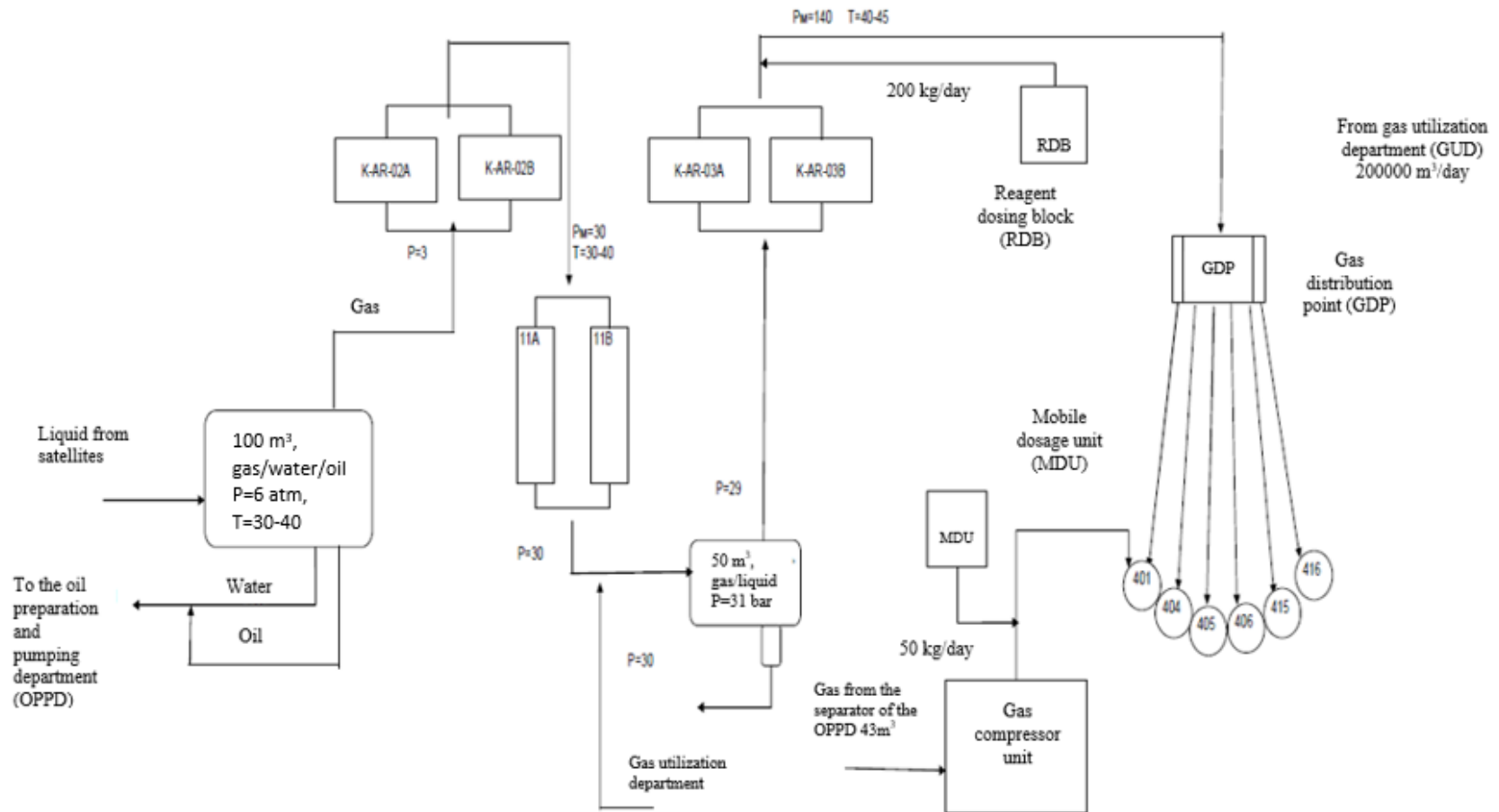
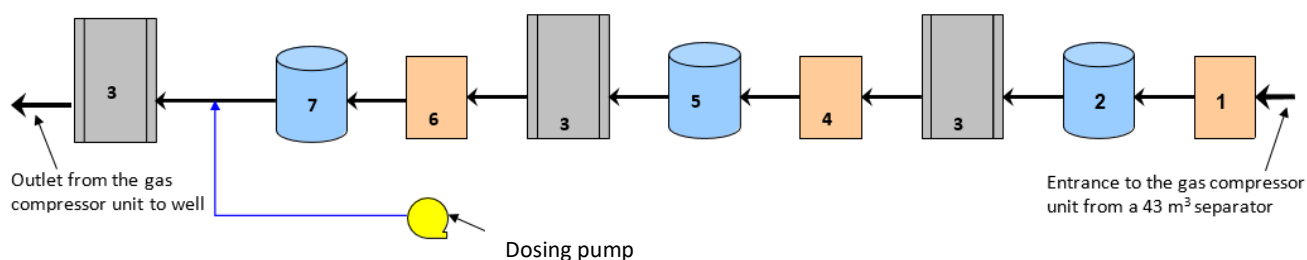**Figure 3.1.1 - Scheme of the gas utilization department**

**Figure 3.1.2 - Scheme of reagent supply to the gas compressor unit of the oil pumping preparation department of the field X**

1 - gas cleaner (mini-separator) of the 1st stage; 2 - 1st stage of compression; 3 - cooling radiator; 4 - gas cleaner (mini-separator) of the 2nd stage; 5 - 2nd stage of compression; 6 - gas cleaner (mini-separator) of the 3rd stage; 7 - 3rd stage of compression

During the tests, the reagent №1 remover of hydrate sediments was dosed continuously. The pressure readings in the experimental section of the pipeline were monitored continuously. During the test, reagent №1 was pumped in at a dosage below the level of the base chemical (Table A.1). According to the readings of the pressure gauges on the experimental section of the pipeline, the dosage of the reagent was varied until the optimal dosage was determined under summer conditions, on average 0.26 g/m$^3$ (Table A.1). The effectiveness of the use of reagent №1 was determined by comparing the readings of the pressure gauges of the experimental section of the pipeline obtained during the tests, with the readings of the pressure gauges of the same pipeline before the use of the reagent №1.

Below is the dosage schedule of reagents in the gas utilization department of field X for June and July of the current year. As can be seen from the above graph, the dosage of the reagent hydrate remover №1 is lower than that of the applied reagent, while the pressure remained stable. (Figure 3.1.3)

According to the readings of the pressure gauges at the gas distribution point, it can be concluded that the pressure on the injection line after the use of reagent №1 remained no higher than 100 bar, which indicates the stability of the gas injection system. (Figure 3.1.4)

In Figure 3.1.5 shows the dependence of the pressures at the outlet of the gas utilization department on the consumption of reagents.

**Figure 3.1.3 - Dosages of reagents in the gas utilization department from 01.06.10 to 24.07.10**

**Figure 3.1.4 - Pressure readings on the manifold for the period of the pilot test from 27.06.10 to 24.07.10.**

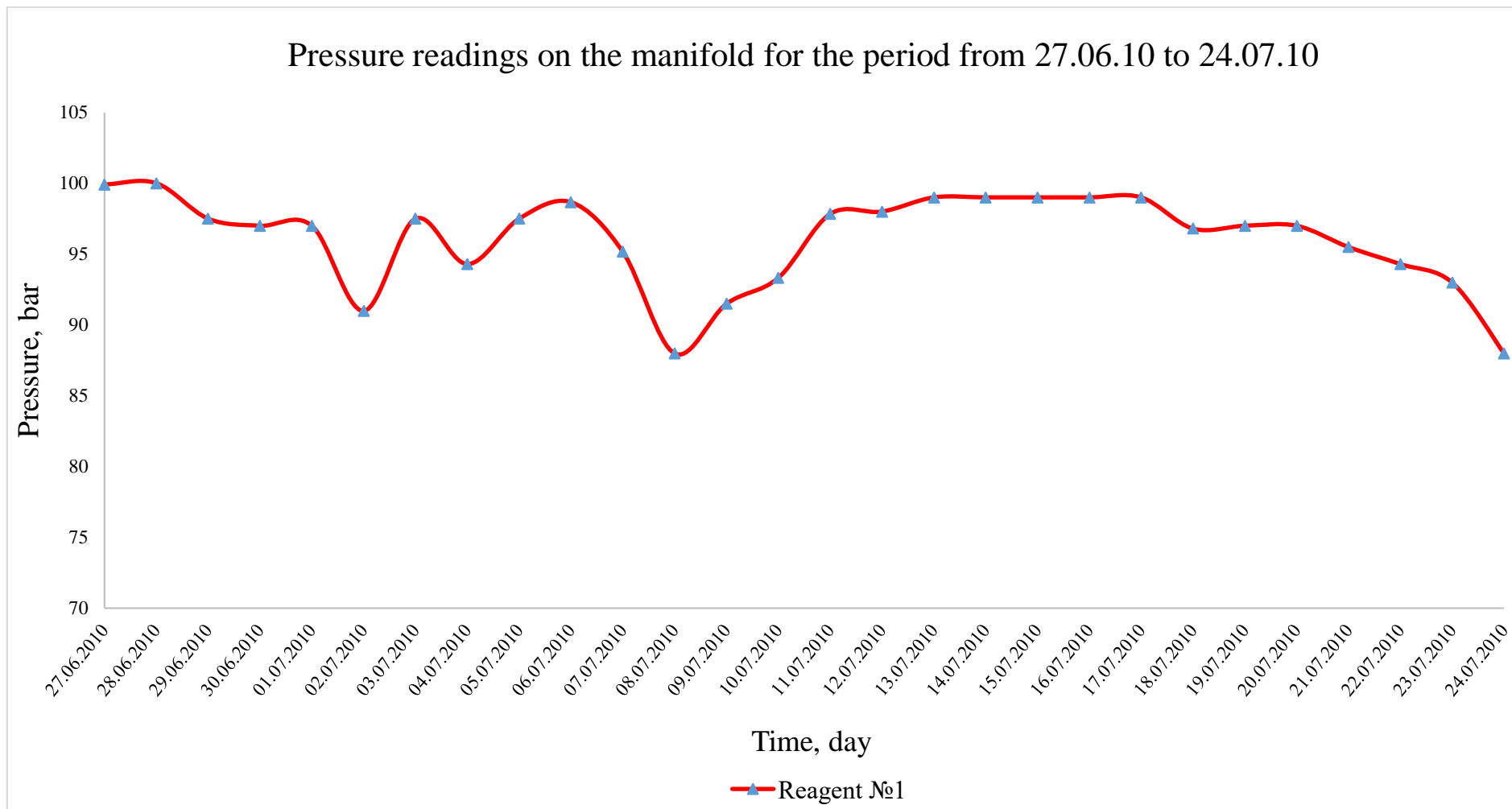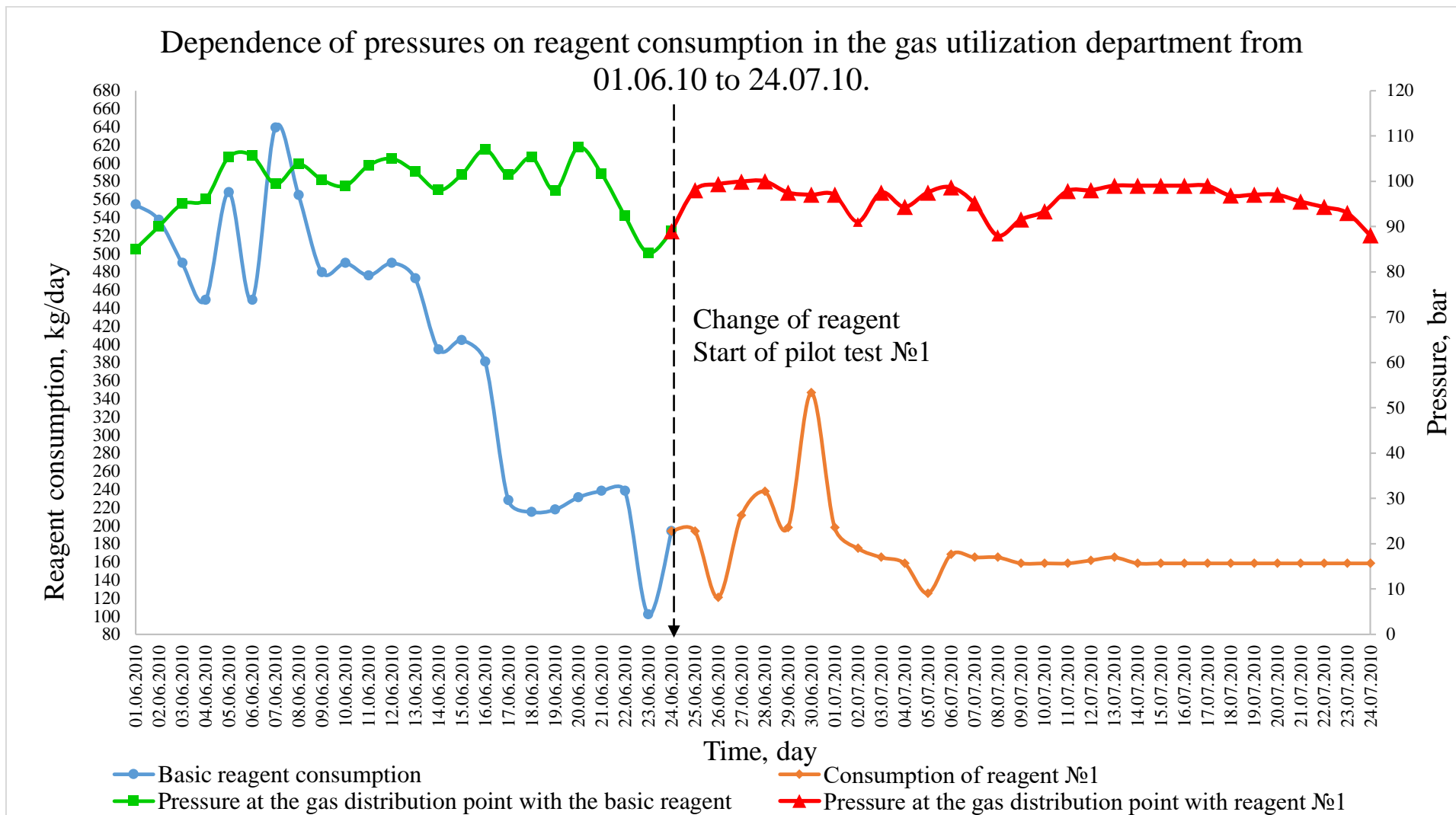**Figure 3.1.5 - Dependence of pressures on reagent consumption in the gas utilization department from 01.06.10 to 27.07.10.**
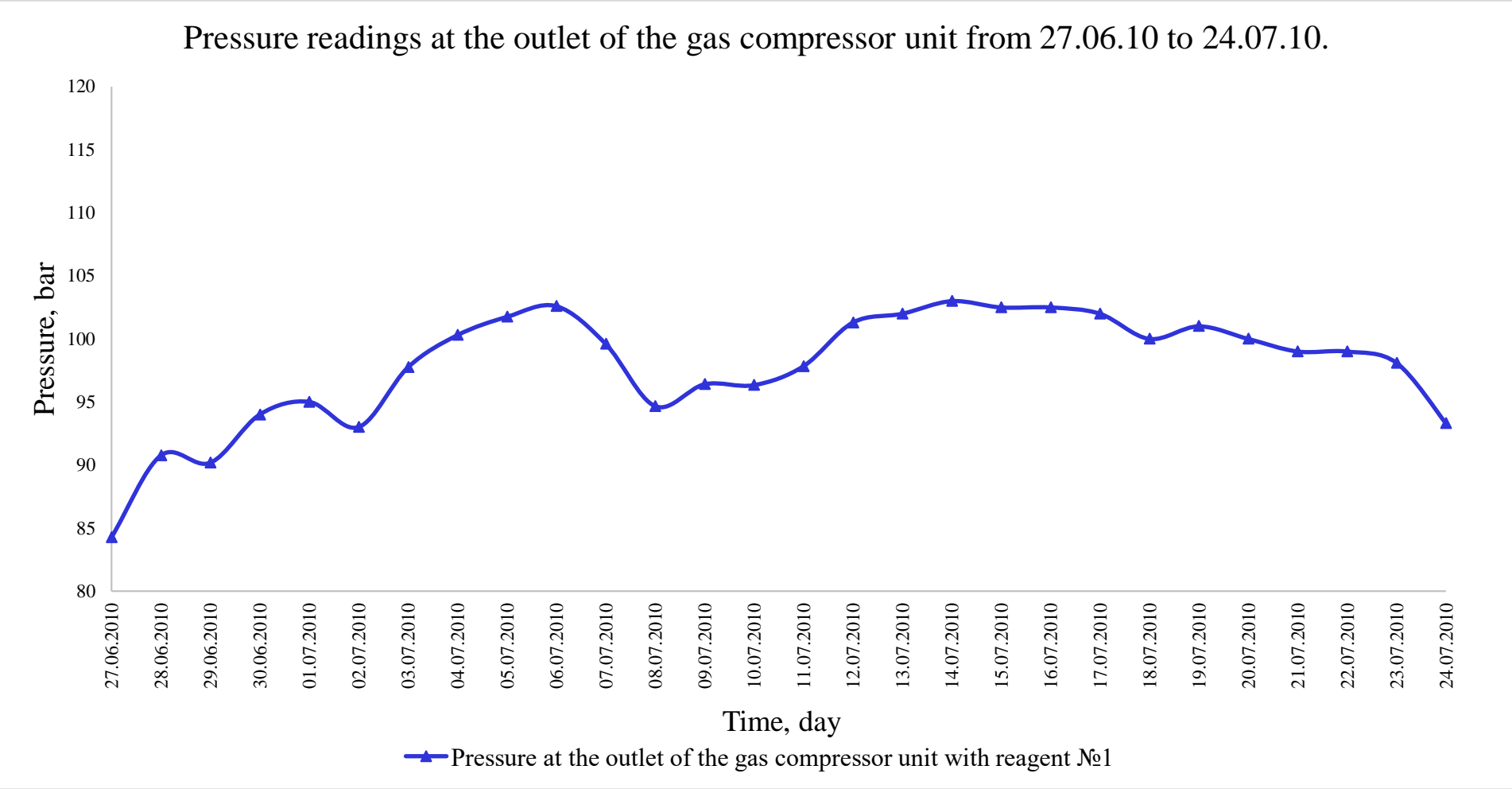
**Figure 3.1.6 - Pressure readings at the outlet of the gas compressor unit during the pilot test from 27.06.10 to 24.07.10.**

From Figure 3.1.6, it is obvious that the pressure on the injection line after the application of reagent №1 remained unchanged, which indicates the stability of the gas injection system.

### 3.2    Pilot test №2 of reagent №2

Basic physical and chemical parameters of reagent №2:

1.    Appearance - transparent homogeneous liquid from yellowish to yellow, odorless.

2.    The density of the inhibitor at 20˚C is within 1200-1300 kg/m$^3$.

3.    Kinematic viscosity at minus 5˚C 6-8 cSt.

4.    Dynamic viscosity at minus 5˚C 7.2-10.4 cPs.

5.    The corrosion rate at 50˚C is not more than 0.05 mm/year, thus, the inhibitor not only prevents hydrate formation, but also provides anticorrosive protection.

6.    Indicator of activity of hydrogen ions (pH) 7-9.

7.    The pour point is not higher than minus 50˚C - (minus 65˚C).

8.    Hazard class -3.

9.    The main components of the inhibitor are inorganic salts (chlorides), which do not affect organic materials.

10.    Some components of the inhibitor can dissolve in TEG (for example, calcium chloride), do not mix with oil (separation occurs with the formation of two liquid phases, no emulsion is formed).

11.    The components of the inhibitor do not mix with the wells produced (delamination occurs with the formation of two liquid phases; no emulsion is formed).

12.    Does not interact with gas condensate and greasy gases, does not form emulsions.

13.    The normal boiling point of the inhibitor is 110-115˚C. There is no cloudiness, precipitation or decomposition.

14.    Highly effective for reducing the equilibrium temperature of hydrate and ice formation of the gas stream.

15.    Fire and explosion proof.

16.    Non-toxic.

17.    The spent inhibitor solution is suitable for regeneration.

18.  Does not have a significant impact on the environment.

19.  Suitable for use in cold climates.

20.  Compatible with methanol in any proportion.

21.  Does not require special storage and transportation conditions.

22.  There is a possibility of organizing local production of the inhibitor near the fields.

The date of the pilot study is from March 23 to April 10, 2017.

The object of testing, according to the required thermobaric conditions, was the connection node of the field X, the diagram is shown in Figure 3.2.1
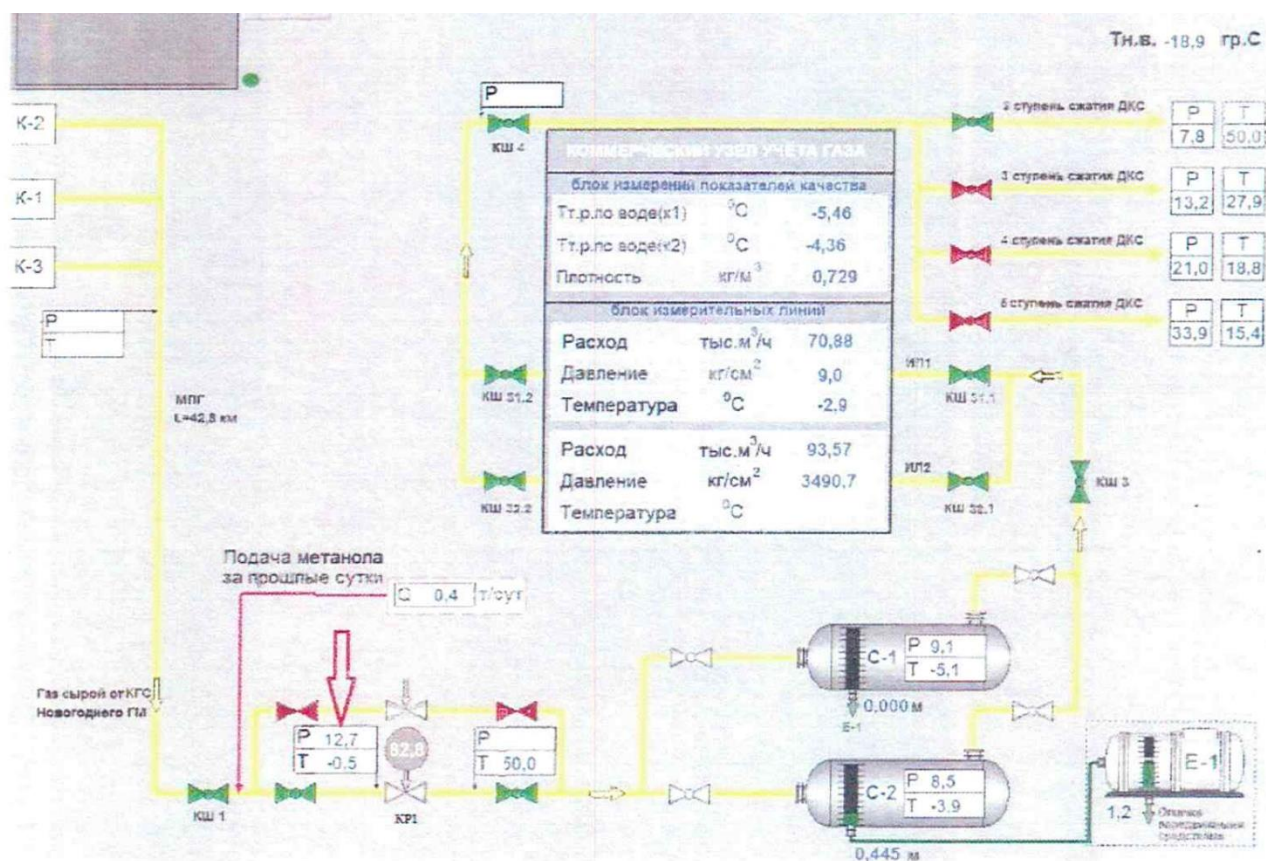


**Figure 3.2.1 - Connection node for field X**

Based on the provided initial data of the connection node, the maximum flow rates of the supplied reagents for inhibition were calculated: for methanol it was 36.6 l/h, for reagent composition №2 - 13.5 l/h. On the basis of the developed schedule, the supply of reagent №2 was periodically changed, starting from 35 l/h with a further decrease to 15 l/h (minimum limitation of the pumping unit supply). During the entire test period, the parameters of the equipment were recorded.

Figure 3.2.2 shows the average actual and calculated inhibitor consumption based on test results.
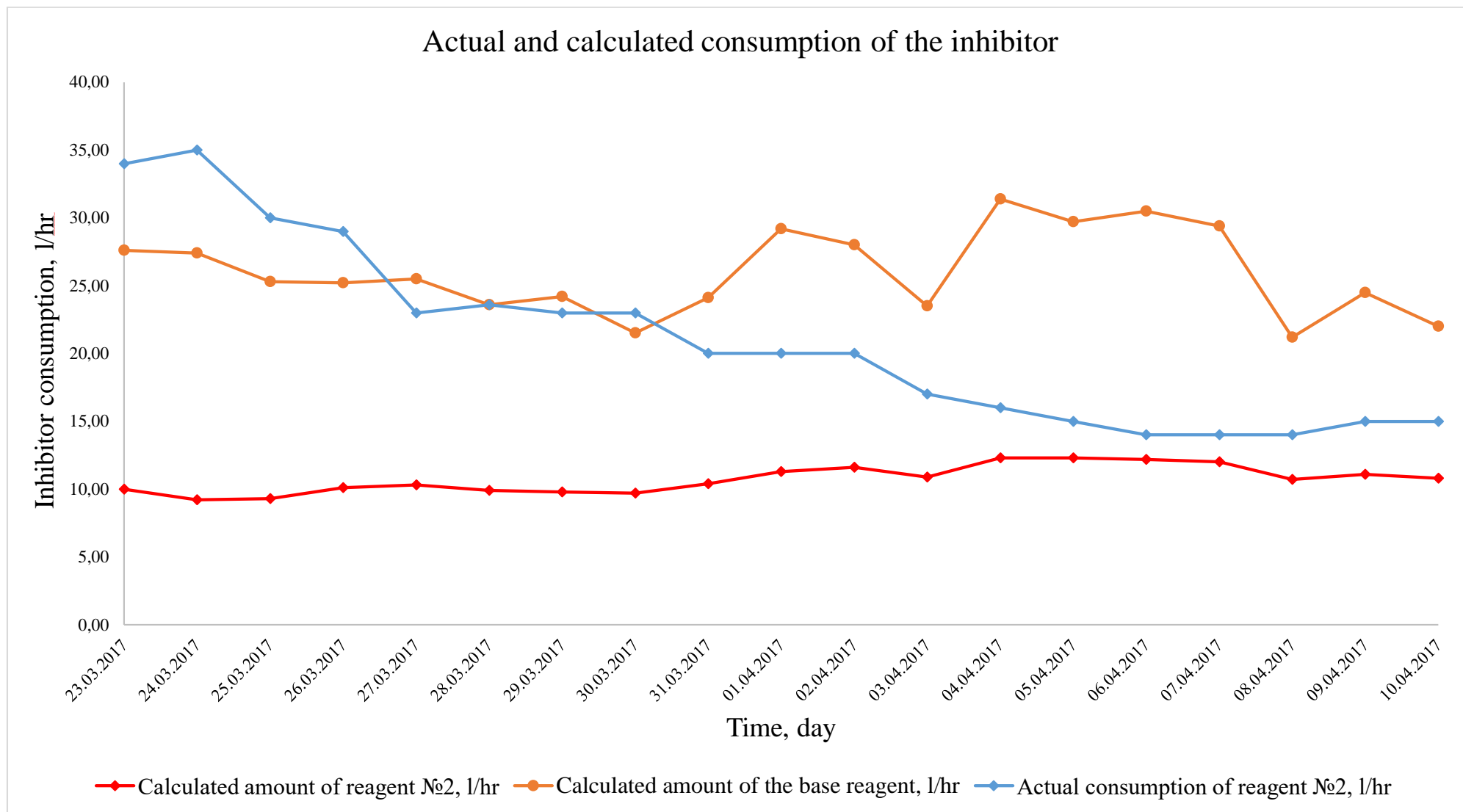
**Figure 3.2.2 - Actual and calculated consumption of the inhibitor during the pilot test from 23.03.17 to 10.04.17.**

### 3.3 Pilot test №3 of reagent №2

**Pilot test task:**

Determination of the effective flow rate and technology (flow rate, holding time) of the use of reagent №2, allowing to ensure uninterrupted transportation of liquid;

The timing of the tests is from 22.11.2017 to 24.12.2017.

**Test object:**

Gas production well X, complicated by the formation of hydrates in field X, was selected for testing, and a constant supply of methanol is used to inhibit it.
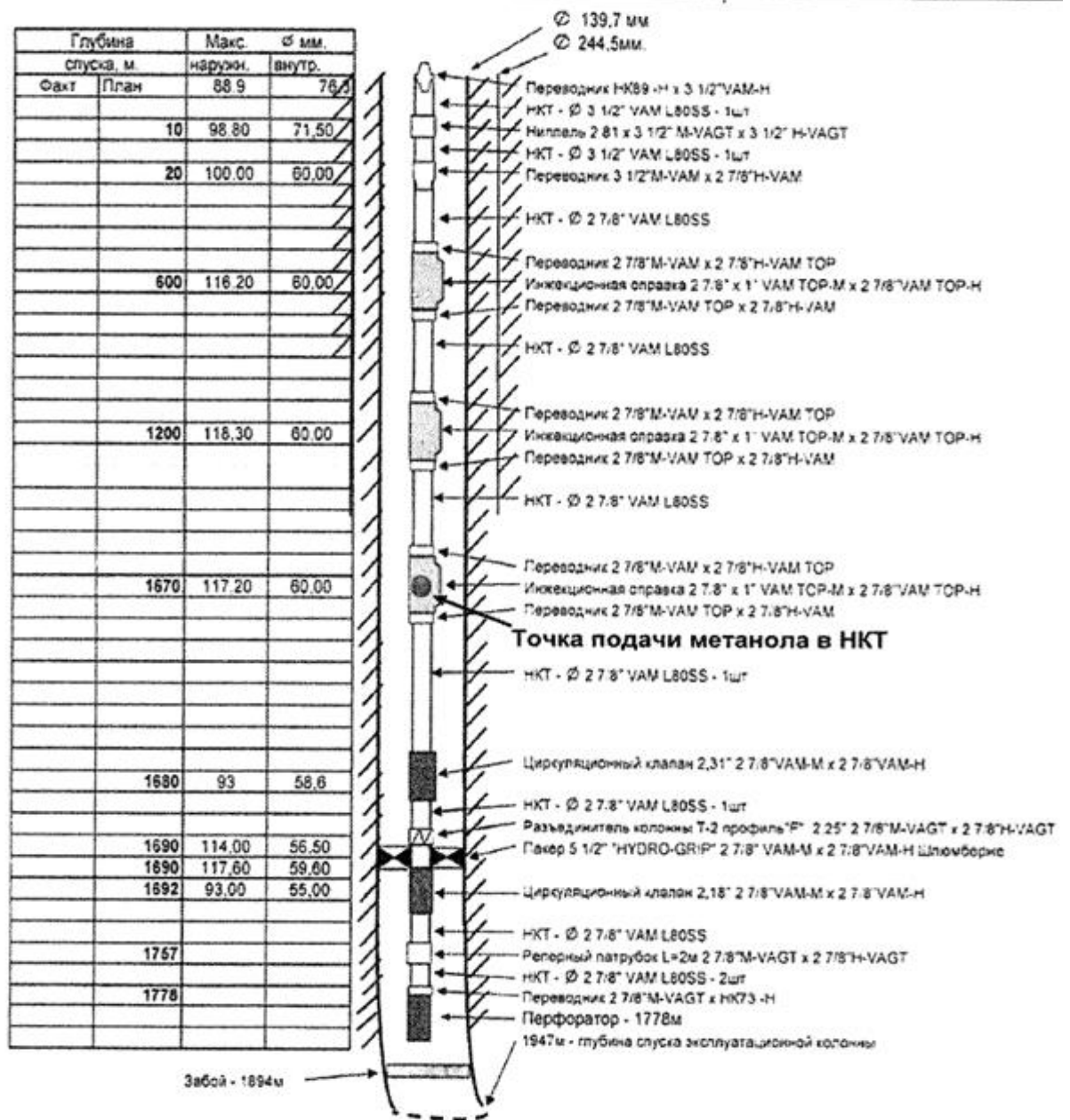


**Figure 3.3.1 - Scheme of the inhibitor supply**

During a pilot test, a minimum temperature of minus 20˚C was recorded.

Based on the provided initial data of the experimental-industrial test object, the maximum flow rates of the supplied reagents for inhibition were calculated: for methanol it was 25 l/h (600 l/day), for reagent composition №2 - 16.6 l/h (400 l/day). Based on the developed schedule, the dosage of reagent №2 was reduced from 29.2 l/h (700 l/day) to 16.6 l/h (400 l/day). During the entire test period, the parameters of the equipment were recorded.

Figure 3.3.2 shows the average actual and calculated inhibitor consumption based on the results obtained during the tests.
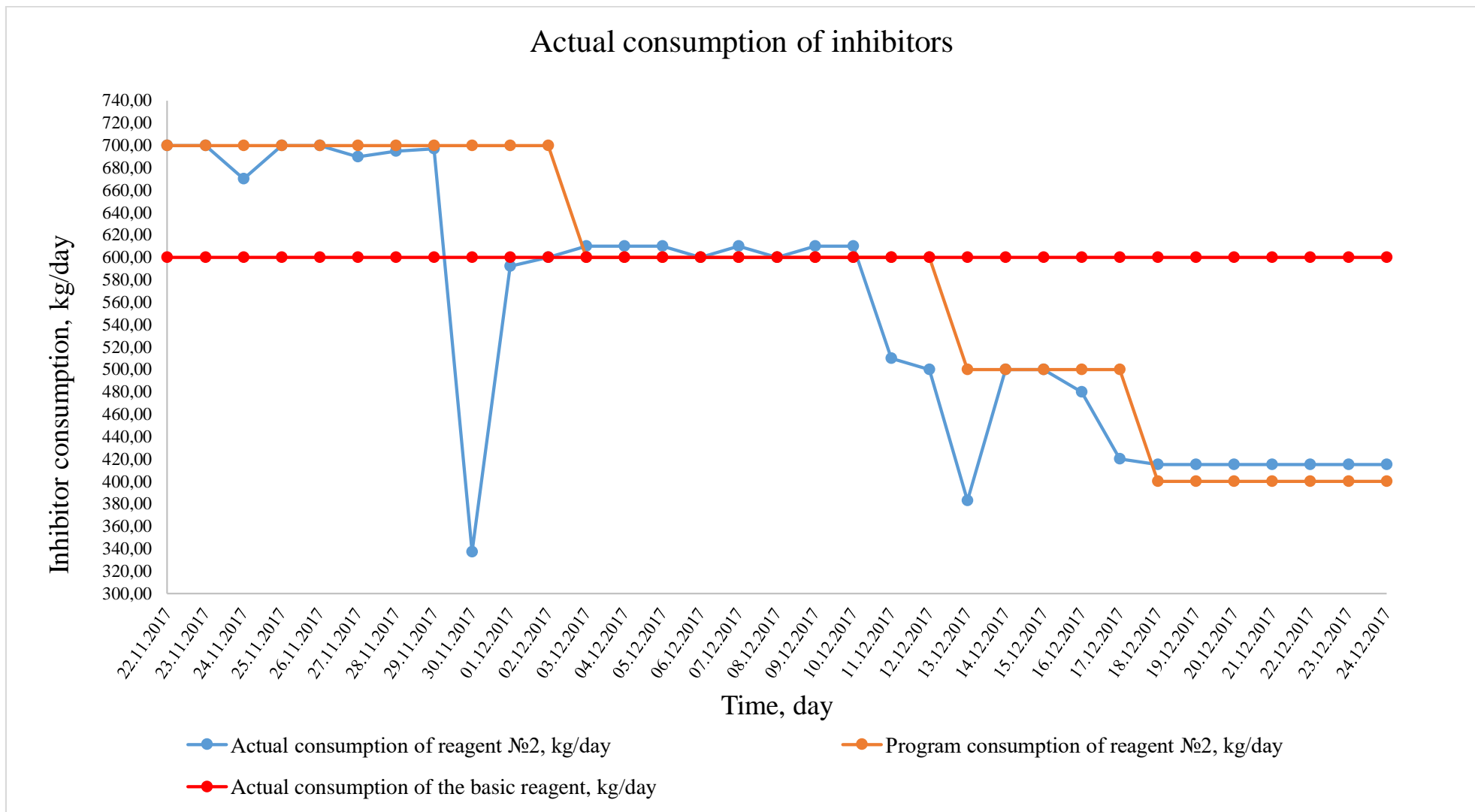
**Figure 3.3.2 - Actual consumption of the inhibitor during the pilot test from 22.11.17 to 24.12.17.**

## 4    Economic part

Table 4.1 shows the cost of a pilot test for the base reagent and reagent №1, taking into account the cost of the inhibitor, its daily consumption and the duration of the pilot test.

**Table 4.1 - Comparative analysis of the basic reagent and reagent №1**

| Parameter | Unit | Reagent №1 | Basic reagent |
|---|---|---|---|
| Cost of the inhibitor | Ŧ/kg | 780 | 785 |
| Consumption of inhibitor | kg/day | 205 | 405 |
| Duration of the pilot test | day | 28 | 23 |
| Cost of the pilot test | Ŧ | 4 477 200 Ŧ | 7 312 275 Ŧ |
| Economy | Ŧ | +2 835 075 Ŧ | -2 835 075 Ŧ |

Table 4.2 presents an economic analysis of the operation of the connection node of the field X for the period from March 23 to April 10, 2017 (19 days in total) and analytical for the whole year, however, it should be taken into account that the norms for inhibition in the winter and summer periods of operation may differ slightly. from those registered at the time of testing.

Consumption of reagent №2 was determined based on the test results, which ended positively. The cost of inhibitors is determined taking into account delivery to the gas field.

**Table 4.2 - Comparative analysis of the basic reagent and reagent №2**

| Name of inhibitor | Price per ton, (with transportation and procurement costs, without VAT) | Reporting period (19 days) | | Reporting period (1 year) | |
|---|---|---|---|---|---|
| | | Consumption of the basic reagent according to the approved standard/Approximate calculation of reagent №2 | Estimated cost | Consumption of the basic reagent according to the approved standard/Approximate calculation of reagent №2 | Estimated cost |
| | thousand ₸ | ton | thousand ₸ | ton | thousand ₸ |
| Basic reagent | 45,5 | 9,336 | 453,068 | 181628 | 8263,7296 |
| Reagent №2 | 47,3704 | 4,862 | 230,3168 | 95835 | 4539,7464 |
| Economy | -1,8704 | 4,474 | 222,7512 | 85793 | 3723,9832 |

### Calculations of economic costs for methanol and calcium chloride injection

As a comparison, she cited economic calculations of operating costs for measures to combat hydrate formation and a comparison of the economic efficiency of inhibitors of hydrate formation when transporting gas through a gas pipeline, such as methanol and calcium chloride.

Initial data:

- The cost of a ton of methanol, $C_{CH_3OH}$ − 156,8 thousand tenge/ton;

- Cost of a ton of calcium chloride, $C_{CaCl_2}$ − 117,6 thousand tenge/ton;

- The amount of methanol, $M_{CH_3OH}$ − 45,6 ton;

- The amount of calcium chloride, $M_{CaCl_2}$ − 246,4 ton;

- the cost of renting a unit for refueling inhibitor tanks, Cr − 11,2 thousand tenge/hour;

- tank volume, $V_t$ − 0.033 m³;

- density of methanol, $\rho_{CH_3OH}$ − 791.8 kg/m³;

- density of methanol, $\rho_{CaCl_2}$ − 1,335 kg/m³.

The economic calculation will be carried out according to the following formulas:

- Total costs (P) are calculated by adding the costs of the inhibitor and the rental of the aggregate:

$$P = P_i + P_a, \text{tenge} \qquad (1)$$

- Inhibitor costs are calculated using the following formula:

$$P = P_i = C_i \times M_i, \text{tenge} \qquad (2)$$

- On average, a filling unit can fill two methanol containers per hour. Let's represent the volume of filling per hour by the formula:

$$V_{hr} = 2 * V_t, \text{m}^3 \qquad (3)$$

We calculate the total operating time of this unit according to the following formula:

$$T_a = \frac{V_{ir}}{2*V_t}, \text{hr} \qquad (4)$$

Where $V_{ir}$ is the amount of inhibitor for refueling, calculated by the formula:

$$V_{ir} = M_p, \text{m}^3 \qquad (5)$$

- The cost of renting a unit is calculated using the formula:

$$P_r = C_r * T_r, \text{tenge} \qquad (6)$$

Since fixed assets are represented by leased property, the amount of depreciation will be the total cost of owning this property. In this case, the equality will be fulfilled:

$$A = P_r, \text{tenge} \qquad (7)$$

**Calculation of economic costs for methanol injection**

1. Determine the cost of methanol:

$P_{CH3OH}$=156,8·45,6=7150,08 tenge

2. Find the volume of methanol for refueling:

$V_{CH3OH}$=45.6*0.7918=57,59 m$^3$

3. Determine the volume of filling in one hour:

$V_{hr}$=2·0,033=0,066 m$^3$.

4. Find the total operating time of the machine:

$T_{CH3OH}$=57,59*0,066=872,58 hr.

5. Determine the cost of renting the unit:

$P_{r\ CH3OH}$=872,58·11,2= 9772,89 thousand tenge

6. Let's calculate the total costs:

$P_{CH3OH}$= 7150,08+9772,89=16922,98 thousand tenge

**Calculation of economic costs for calcium chloride injection**

1. Determine the cost of calcium chloride:

$P_{CaCl2}$=117,6·246,4=28976,64 thousand tenge

2. Find the volume of calcium chloride for refueling:

$V_{CaCl2}$=246,4*1,335=184,57 m$^3$

3. Determine the volume of filling in one hour:

$V_{hr}$=2·0,033=0,066 m$^3$

4. Find the total operating time of the machine:

$T_{CaCl2}$=184,57*0,066=2796,50 hr

5. Determine the cost of renting the unit:

$P_{r\ CaCl2}$=2796,50·11,2=31320,85 thousand tenge

6. Let's calculate the total costs:

$P_{CaCl2}$=28976,64 + 31320,85 = 60297,49 thousand tenge

The calculation results are presented in Table 4.3

**Table 4.3 - The results of calculating the economic costs of using inhibitors**

| Parameter | Unit | Methanol | Calcium chloride |
|---|---|---|---|
| Inhibitor costs | thousand tenge/ton | 156,8 | 117,6 |
| Inhibitor consumption | thousand tenge | 7150,08 | 28976,64 |
| Inhibitor weight | ton | 45,6 | 246,4 |
| Amount of inhibitor for filling | $m^3$ | 57,59030058 | 184,5693 |
| The cost of renting a car for refueling the inhibitor | thousand tenge/hour | 11,2 | 11,2 |
| Unit rental costs | thousand tenge | 9772,899493 | 31320,85 |
| Filling volume for 1 hour | $m^3$ | 0,066 | 0,066 |
| Total machine running time | hour | 872,5803118 | 2796,504 |
| Total consumption | thousand tenge | 16922,97949 | 60297,49 |
| Economy | thousand tenge | 43374,50945 | |

Based on the calculation of economic costs, it can be said that the costs of using calcium chloride are 3.5 times higher than the costs of using methanol, this is due to the fact that calcium chloride is needed to prevent hydrate formation 5 times more than methanol. Hence, it can be concluded that the use of methanol to combat hydrate formation is more economical than the use of calcium chloride, despite the fact that the wholesale price of the latter is 25% lower.

## 5    Results and discussion

**Results of pilot tests №1 of reagent №1:**

Reagent №1 removes and prevents the formation of hydrates on the discharge line of the gas utilization department (GUD) and the gas compressor unit (GCU) at a dosage of 0.26 g/m$^3$ lower than that of the base reagent 0.63 g/m$^3$, which is quite effective technologically and economically.

**Resume:**

The formation of hydrates in the process equipment of field X is a serious problem and the use of an anti-hydrate reagent is urgently needed.

The protective effect of reagent №1 is 100% at a dosage of 0.26 g/m$^3$ in summer conditions, which is quite effective in the conditions of the field X.

Based on the data obtained from Table 10, we conclude that it is economically profitable to combat hydrate formation using reagent №1 for 2835075 tenge.

**Results of pilot tests №2 of reagent №2:**

•       The use of reagent №2 at the connection point for field X is economically feasible, based on Table 4.2.

•       The reagent does not require a complex control scheme during transportation (transported by all types of transport), storage and use, it is safe for humans and the environment.

•       According to the test results, no deviations in the technological regime, a reduction in gas consumption, an increase in the pressure drop across the throttling device were observed.

•       When the separation water was drained from the horizontal separators of the field X connection unit, no foaming or emulsion formation was found.

•       For the period from March 23 to April 10, 2017 (19 days in total), 9.336 tons of reagent were used with a change in the supply volume from 35 to 15 l/hr., which corresponds to the threshold values of the pumping equipment productivity. At the same time, the calculated amount of the inhibitor was 4.862 tons with a change in the feed volume from 13.5 to 8.5 l/hr.

•       The maximum pressure drop across the valve of the regulator №1 for the period from March 23 to April 10, 2017 was 4.3 kg*sec/cm$^2$. The maximum difference in outdoor temperature for the period from March 23 to April 10, 2017 was 11.2˚C.

•       The consumption of the basic reagent at the facility before the start of pilot testing of reagent №2 was 30 l/hr.

- It is recommended to replace the basic reagent with a prototype.

**Results of pilot tests №3 of reagent №2:**

- The use of reagent №2 at well X is economically feasible. The reagent does not require a complex control scheme during transportation (transported by all types of transport), storage and use, it is safe for humans, the environment and equipment.

- According to the test results, no deviations in the technological regime, reduction of gas flow rate, accumulation of reagent at the bottom hole were observed.

- During the primary separation of oil at the inlet separator of the oil treatment unit, no foaming or formation of an emulsion with oil was found.

- The application equipment worked normally, without any remarks.

- The minimum supplied consumption of reagent №2 occurred on November 30, 2017 (14.0 l/h, 337 l/day) and on December 13, 2017 (15.9 l/h, 383 l/day).

- The maximum difference in outdoor air temperature for the period from November 22 to December 24, 2017 in the daytime 8.4, at night 10.5°C.

- The consumption of methanol at the facility before the start of pilot testing of reagent №2 was 25 l/h (600 l/day).

Potential area of application: Designed to prevent gas hydrate deposits in the tubing of producing gas wells. The approximate number of wells in the X field, where this chemical can be used. the reagent is - 230 wells (the economic effect of potential implementation from 1 well is approximately 3816.68 thousand tenge per year).

Assessment of technological and economic efficiency:

During the period from November 22 to December 24, 2017 (32 days in total), 18,129 liters of reagent were used when the delivery volume changed from 29.2 to 17.3 liters/hour. In total, 33,000 liters of reagent were used, taking into account the flushing of the well from basic reagent.

Calculation of economic efficiency, according to which the economic effect for the test period amounted to 202.272 thousand tenge, with a reporting period equal to one year, the savings will amount to 3816.68 thousand tenge.

According to the results of the conducted tests of the inhibitor of hydrate formation, reagent №2 is recommended for implementation.

**Table 5.1 - The results of the pilot tests №2 and №3 with reagent №2**

| Name of inhibitor | Pilot test №2 | | Pilot test №3 | |
|---|---|---|---|---|
| | Consumption of the basic reagent according to the standard / actual calculation of the reagent №2 | Inhibition costs incurred relative to basic reagent | Consumption of the basic reagent according to the standard / actual calculation of the reagent №2 | Inhibition costs incurred relative to basic reagent |
| Units | m³ | % | m³ | % |
| Basic reagent | 12,605 | 100% | 19,243 | 100% |
| Reagent №2 | 3,74 | 51% | 13,28 | 80% |
| Economy | 8,865 | 49% | 5,963 | 20% |

During the pilot test №2 period, when using reagent №2 the savings compared to the basic reagent amounted to 49 %. During the pilot test №3 period, when using reagent №2 the savings compared to the basic reagent amounted to 20 %. Consumption of the basic reagent in both cases exceeds the actual consumption of the tested reagent №2.

# CONCLUSION

Having considered the methods of combating hydrate formation in the systems of production, preparation and transportation of natural gas, we can conclude that the main method for preventing hydrate formation and hydrate deposition is the use of hydrate inhibitors.

Physical methods for dealing with hydrates are difficult to implement, since heating pipelines is a very laborious and expensive process. Technological methods require constant monitoring and regulation of pressure and temperature, which is not always possible in the X-field.

According to the results of three pilot tests, the effectiveness of the use of inhibitors (reagent №1, reagent №2) to combat hydrate formation in the field X was proved. This method of using hydrate inhibitors is economically beneficial. In addition to the low cost of the inhibitor relative to the cost of the base reagent, we observe a low consumption of reagents, a stable level of gas supply without pressure drops. The process of removing hydrate plugs is easier, namely, by introducing an inhibitor into the pipeline through special nozzles, pressure gauge fittings or through a purge plug. The reagents have not corrosion effect on the pipeline, does not cause salt deposits on the equipment, suitable for regeneration, highly effective for reducing the equilibrium temperature of gas flow hydrate formation, have low freezing point and can be used at high reservoir pressures and does not require special storage and transportation measures.

# REFERENCES

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# APPENDIX A

## Table A.1 - Data on the control of the use of the reagent at the gas utilization department of field X for June and July 2010

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Total | Average (current reagent) | Average (X reagent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical, kg/day | 554,2 | 537,2 | 489,6 | 448,8 | 567,8 | 448,8 | 639,2 | 564,4 | 479,4 | 489,6 | 476 | 489,6 | 472,6 | 394,4 | 404,6 | 380,8 | 227,8 | 215,05 | 217,6 | 231,2 | 238 | 238 | 102 | 193,98 | 193,98 | 120,84 | 211,2 | 237,6 | 198 | 346,5 | 10809 | 404,637 | 248,325 |
| Total gas injection, m3/day CGF | 623000 | 551000 | 527000 | 582000 | 605200 | 461300 | 612200 | 617000 | 735000 | 758000 | 707000 | 769000 | 649000 | 743000 | 684000 | 700000 | 630000 | 690000 | 580000 | 715000 | 699000 | 652000 | 556000 | 605000 | 725000 | 665000 | 759000 | 782000 | 789000 | 780000 | 2E+07 | 645465 | 777500 |
| Dosage, g/1000m3 | 889,57 | 974,95 | 929,03 | 771,13 | 938,2 | 972,9 | 1044,1 | 914,75 | 652,24 | 645,91 | 673,27 | 636,67 | 728,2 | 530,82 | 591,52 | 544 | 361,59 | 311,67 | 375,17 | 323,36 | 340,49 | 365,03 | 183,45 | 320,63 | 267,56 | 181,71 | 278,26 | 303,84 | 250,95 | 444,23 | 16745 | 639,044 | 319,32 |
| Gas pressure at the manifold (gas distribution point) average | 85 | 90 | 95 | 96 | 105,33 | 105,67 | 99,4 | 103,75 | 100,33 | 99 | 103,5 | 105 | 102,08 | 98 | 101,5 | 107 | 101,5 | 105,25 | 97,91 | 107,5 | 101,66 | 92,33 | 84,16 | 88,91 | 98 | 99,33 | 99,91 | 100 | 97,5 | 97 |  | 99,4291 | 98,6025 |

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Total |  | Average (X reagent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical, kg/day | 198 | 174,9 | 165 | 158,4 | 125,4 | 168,3 | 165 | 165 | 158,4 | 158,4 | 158,4 | 161,7 | 165 | 158,4 | 158,4 | 158,4 | 158,4 | 158,4 | 158,4 | 158,4 | 158,4 | 158,4 | 158,4 | 158,4 |  |  |  |  |  |  | 3864,3 |  | 161,013 |
| Total gas injection, m3/day CGF | 665200 | 556000 | 643000 | 578000 | 695000 | 612000 | 556000 | 457000 | 449500 | 563500 | 691000 | 636000 | 694000 | 693000 | 716000 | 723000 | 723000 | 689000 | 698000 | 730000 | 747200 | 728000 | 581000 | 550000 |  |  |  |  |  |  | 2E+07 |  | 640600 |
| Dosage, g/1000m3 | 297,65 | 314,57 | 256,61 | 274,05 | 180,43 | 275 | 296,76 | 361,05 | 352,39 | 281,1 | 229,23 | 254,25 | 237,75 | 228,57 | 221,23 | 219,09 | 219,09 | 229,9 | 226,93 | 216,99 | 211,99 | 217,58 | 272,63 | 288 |  |  |  |  |  |  | 6162,8 |  | 256,785 |
| Gas pressure at the manifold (gas distribution point) average | 97 | 91 | 97,5 | 94,3 | 97,5 | 98,66 | 95,16 | 88 | 91,5 | 93,33 | 97,83 | 98 | 99 | 99 | 99 | 99 | 99 | 96,8 | 97 | 97 | 95,5 | 94,3 | 93 | 88 |  |  |  |  |  |  |  |  | 95,6825 |

**Table A.2 - Data on the control of the use of the reagent at the gas compressor unit of the field X**

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Total | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical, kg/day | 37,4 | 43,35 | 20,4 | 39,1 | 28,05 | 18,7 | 27,2 | 8,5 | 0 | 57,8 | 20,4 | 20,4 | 25,5 | 39,1 | 18,7 | 42,5 | 57,8 | 30,6 | 51 | 34,85 | 61,2 | 61,2 | 51 | 51 | 51 | 46,75 | 92,65 | 89,25 | 57,75 | 133,7 | 1125 | 41,68 |
| Total gas injection, m3/day AK-AS-01 on well 401 AK | 78000 | 78000 | 78000 | 78000 | 48300 | 53200 | 78000 | 43500 | 0 | 25400 | 77700 | 78000 | 78000 | 78000 | 76500 | 48700 | 75800 | 78000 | 54900 | 51600 | 73800 | 74650 | 74400 | 74400 | 74100 | 66500 | 45900 | 42000 | 30000 | 70400 | | 63691 |
| Dosage, g/1000m3 | 479 | 556 | 262 | 501 | 581 | 352 | 349 | 195 | | 2276 | 263 | 262 | 327 | 501 | 244 | 873 | 763 | 392 | 929 | 675 | 829 | 820 | 685 | 685 | 688 | 703 | 2019 | 2125 | 1925 | 1898 | | 716,1 |
| Gas pressure at the compressor outlet K-AS-01, bar | 95,41 | 95,66 | 100,7 | 94,16 | 113 | 100 | 95,25 | 105 | | 109,5 | 104,9 | 107,4 | 97,08 | 101 | 108,3 | 107,2 | 105,4 | 103,2 | 105,8 | 97,2 | 106,8 | 96,9 | 101,8 | 92,58 | 106,7 | 111,2 | 84,25 | 90,75 | 90,17 | 94 | | 101,4 |

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Total | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical, kg/day | 56,1 | 56,63 | 51,15 | 52,8 | 49,5 | 29,7 | 41,25 | 47,89 | 41,25 | 37,95 | 41,25 | 31,35 | 36,3 | 29,7 | 30,5 | 29,7 | 44,55 | 29,7 | 29,7 | 25,58 | 47,85 | 30,53 | 26,4 | 23,1 | | | | | | | 317,6 | 42,76 |
| Total gas injection, m3/day AK-AS-01 on well 401 AK | 80000 | 80100 | 80000 | 80000 | 80600 | 80500 | 79900 | 71800 | 74200 | 75900 | 77700 | 74700 | 71900 | 72700 | 73200 | 72000 | 72500 | 72500 | 73000 | 73800 | 76200 | 74800 | 70000 | 75900 | | | | | | | | 75579 |
| Dosage, g/1000m3 | 701 | 707 | 639 | 660 | 614 | 369 | 516 | 667 | 556 | 500 | 531 | 420 | 505 | 409 | 417 | 413 | 614 | 410 | 407 | 347 | 628 | 408 | 377 | 304 | | | | | | | | 505 |
| Gas pressure at the compressor outlet K-AS-01, bar | 95 | 93 | 97,75 | 100,3 | 101,8 | 102,6 | 99,6 | 94,66 | 96,4 | 96,33 | 97,83 | 101,3 | 102 | 103 | 102,5 | 102,5 | 102 | 100 | 101 | 100 | 99 | 99 | 98,1 | 93,3 | | | | | | | | 99,12 |