University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

MASTER'S THESIS

Study programme/specialisation: Marine and Offshore Technology	Spring/ Autumn semester, 2021 Open / Confidential
Author: Arseniy Zhagrin	
Programme coordinator: Dr. Lin Li Supervisor(s): Dr. Lin Li (UiS), Anatoly Borisovich Zolotukhin (Gubkin University)	
Title of master's thesis: APPLICATION OF TRACER TECHNOLOGY ON THE PRIRAZLOMNOYE OIL FIELD FOR IMPROVING THE FIELD PRODUCTION.	
Credits: 30 ECTS	
Keywords: Tracer, Prirazlomnoye field, Horizontal well, Tubing, Hydraulic fracturing	Number of pages: …57………… + supplemental material/other: ………… Stavanger, …15.06.2021….. date/year

ABSTRACT

Prirazlomnoye oil field is the only field on the Arctic shelf of Russia, where oil production has already begun. Oil production at this field is complicated by both weather and marine production conditions. Oil production at this field is carried out using horizontal wells with multi-stage hydraulic fracturing. In such type of wells, there is a problem of the correct fluid flow profile determination in the well. For this purpose, tracer (indicator) studies are carried out.

The relevance of the work is due to the growth of oil production in offshore fields every year. Technologies for oil and gas production do not stand still and are being improved in various directions. For example, tracer technologies are a modern method of studying the whole reservoir of the field and the wells separately.

At present, there is an urgent need to quickly obtain information that helps to extract hydrocarbons safely and most effectively from the earth's interior.

The Master Thesis describes the Pechora Sea environmental conditions. The method of tracer studies at the Prirazlomnoye oil field is described. The analysis of the results obtained after selecting and examining samples by the laboratory method was carried out. The operating intervals of wells and the flow rate of each interval are determined. Finally, recommendations for further tracer studies of the well are given.

ACNOWLEDGEMENTS

I would like to express my gratitude to the University of Stavanger and the Gubkin University for giving me an opportunity to gain useful knowledge, new life experience and opportunity to become an engineer.

I would like to thank my scientific advisors Professor Anatoly Zolotukhin and Dr. Lin Li. I am very appreciate their patience and support during study in university. It was a great honor for me to study in this joint program.

I would like to express my deepest gratitude to my family for helping me in the most difficult times. Quite a few difficulties were passed, and now I am already a graduate.

TABLE OF CONTENTS

DEFINITIONS, SYMBOLS, AND ABBREVIATIONS

MSHF – Multi-stage hydraulic fracturing;

HF – Hydraulic fracturing;

CAPEX – Capital investment;

OIRFP - Offshore ice-resistant fixed platform;

ARCO – Arctic Oil;

SPE – Society of Petroleum Engineers;

AIME – American institute of mining engineers;

WS – Water System;

OS – Oil System.

LIST OF DRAWINGS

LIST OF TABLES

1. INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

The Prirazlomnoye field is currently the only project in Russia for the production of hydrocarbons on the Arctic shelf. The main facility of the field is the Prirazlomnoye offshore ice-resistant oil production platform.

The Prirazlomnoye oil-producing offshore ice-resistant stationary platform (OIRFP) was created specifically for the development of the Prirazlomnoye field. It ensures the execution of all technological operations: drilling, production, oil storage, preparation, and shipment of finished products. Prirazlomnoye was designed considering the characteristics of the Arctic region and is designed to operate in extreme climatic conditions, meets the most stringent safety requirements and can withstand maximum ice loads.

The wellheads of all wells that are planned to be drilled in the field are located inside the platform - its base is also a buffer between the well and the open sea. In addition, the equipment installed in the wells is designed to prevent the possibility of an uncontrolled release of oil or gas. The offloading line for pumping oil to the tanker is equipped with an emergency stop and shutdown system that works instantly.

In this work, it is proposed to introduce tracer probes into the bottomhole zone of the wells, which are necessary to control the oil inflow. In more detail, tracer indicators serve to reduce the crater created by the depression on the oil formation.

The main motivation is to reduce the depression funnel, which will help to develop the field more efficiently and environmentally.

1.2 GENERAL CHARACTERISTICS OF OIL FIELD

1.2.1 FEATURES OF OFFSHORE OIL FIELDS

The continental shelf consists of the underwater border of the mainland adjacent to the territorial boundaries of the waters. The edge of the continental shelf is characterized by the subsoil of the underwater regions, including the sea and ocean bottom, where the angle of inclination often changes in relief. The largest is the continental Shelf of Siberia. The shelf area under the jurisdiction of the Russian Federation is 20% of the total area of the Shelf of the World Ocean. The Siberian Shelf is the least developed and explored; in general, the study and development of deposits in the depths of the seas and oceans, both oil and gas, involves colossal investments. Costs are driven by a variety of reasons and conditions, such as [1]:

- Continental and weather conditions;
- Depth and distance of the deposit from the coastline;
- Hydrocarbon resources produced;
- Well production rates;
- Scientific and technological progress of the industrial activity.

Despite the enormous costs, the development of hydrocarbons by this kind of technology brings significant advantages.

From the specifics of the development of offshore oil and gas fields, I would like to highlight the following features:

Operation of all kinds of water fill equipment for the construction of oil field facilities at offshore fields and their maintenance, for example, crane installation vessels, pipe laying barges.

Drilling of a bush of inclined wells from individual stationary platforms, from backstage sites, on artificially created islands, from self-lifting and semi-submersible floating installations and other structures both above water and underwater;

A rational approach to selecting a well grid when designing a specific deposit or deposit: a grid is needed that does not need subsequent compaction.

Selection of suitable installations and structures, floating production decks, and other structures to locate an acceptable number of wells. But the above points depend primarily on factors such as:

• deadlines

• distance between mouths

• formation occurrence, etc.

Complimentary strength and viability of structures of the duration of development of oil and gas fields.

Forcing the development and construction of wells through the production of high-quality technical equipment and innovation, keeping pace with drilling technologies of inclined sighting wells with the necessary deviation from the vertical and ensuring the autonomy of the work of drilling crews. Moreover, the operation should not be disrupted due to the hydrometeorological conditions of the sea. According to the type of outstretched in close conditions, platforms, all kinds of sites, make it possible to complete the drilling of all designed wells in the shortest period and then go to their development without the need for one-time drilling and operation. Factors are impeding the development of offshore deposits.

Several circumstances aggravating the development of the subsoil of oil and gas fields arise. I want to highlight the main ones:

- Heterogeneity of filtration-capacitive properties of the deposit;
- The unfavorable ratio of mobility of phases filtered in the formation;
- Gravitational phase separation, which leads to preferential filtration of gas along the upper part of the formation, and water along its lower part.

1.2.2 GENERAL INFORMATION OF FIELD AND PLATFORM

Prirazlomnoye oilfield is the first and only existing project for oil production on the Shelf of the Russian Arctic. Recoverable reserves of this field amount to 70 million tons of oil. The main object of the field is the offshore ice-resistant oil production platform Prirazlomnoye. Prirazlomnoye is a unique platform designed as safely as possible for both humans and the environment, which is why the principle of "zero discharge" is used: industrial and household waste is to be processed and disposed of by being taken ashore or pumped into the formation. The Prirazlomnoye platform on the Shelf of the Russian Arctic produced the first oil, and the experience gained during the development of the Prirazlomnoye field helps develop new fields.

The Prirazlomnoye platform is an artificial island in the Pechora Sea, 60 kilometers from the coast. The Pechora Sea lies on the continuation of the Timan-Pechora oil and gas province with a high density of initial total hydrocarbon reserves. The temperature can reach -480S degrees, and waves of 9 meters, torsos up to 2 meters. Although natural and climatic conditions are considered problematic, they are distinguished by long preservation of the ice sheet - a little more than six months (from October to July, the ice season lasts). The system of currents includes the full spectrum of seawater movement. Quasi-stationary circulation, synoptic-scale currents and tidal currents are also observed here. The ice-resistant platform is installed at the bottom, at a depth of 20 meters. This allows drilling wells inside the platform. The base has the role of protection - barriers between the well and the open sea [1].

In total, 200 people produce oil at Prirazlomnoye around the clock. The method of storing oil is "wet" which implies a constant filling of reservoirs with oil or water to prevent an explosive medium.

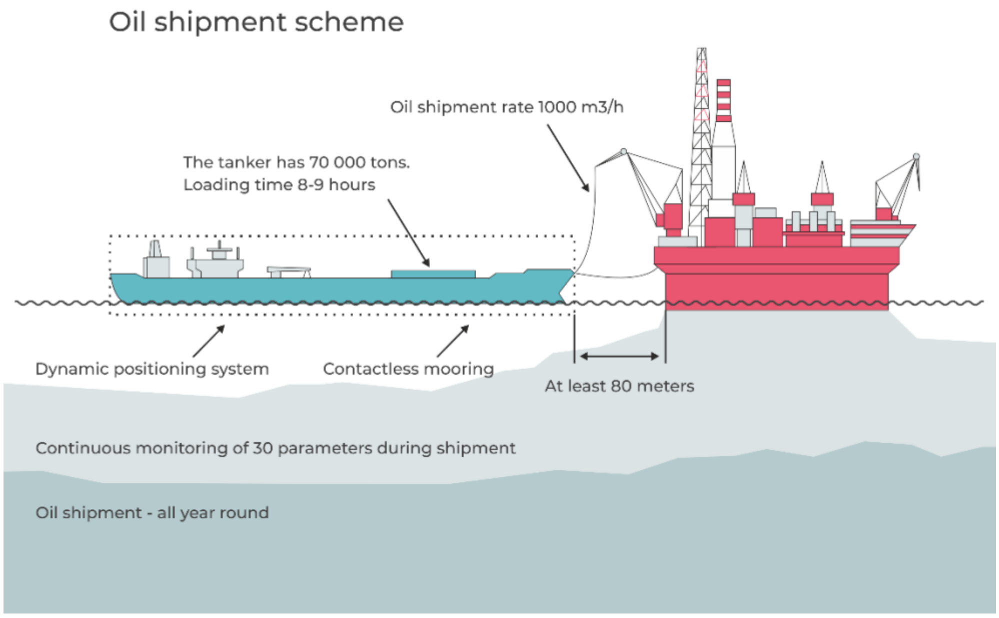

Figure 1.1 Scheme of oil shipment from the platform

For the 2020 year, the number of wells reached 32. The shipment of the tanker takes an average of 8-9 hours and requires control of 30 parameters.

Figure 1.2 shows the parameters that help monitor the platform's overall state and maintain its safe life.

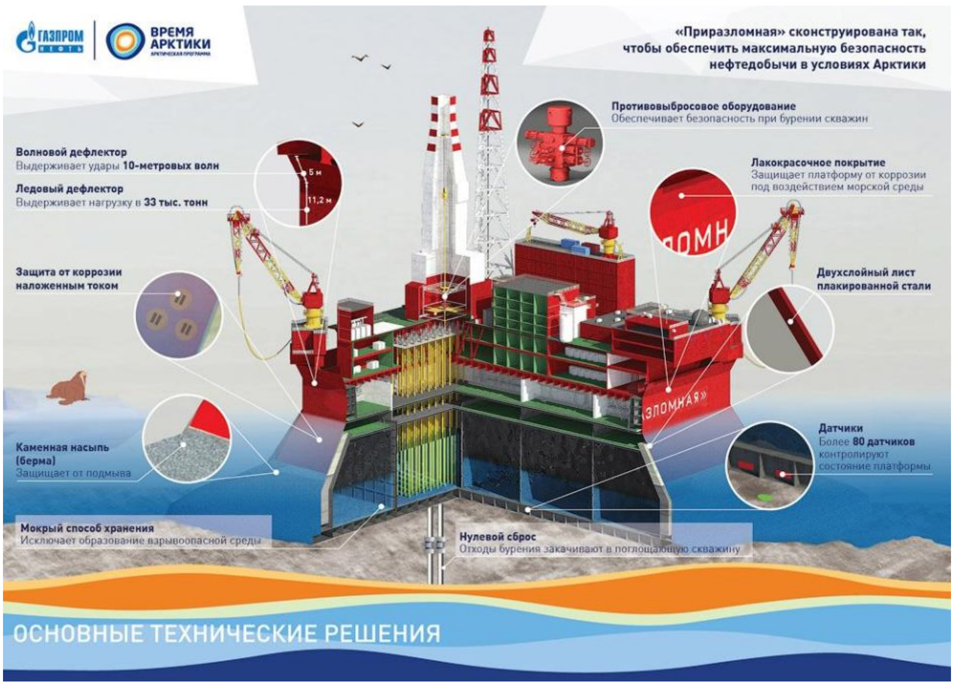

Figure 1.2 Platform security monitoring scheme [2]

Several parameters monitor the general state of the platform at once:

• soil dynamometer - ground load measurement,

• strain sensors - measurement of ice loads,

• inclinometer - measurement of caisson inclination,

•accelerometer - seismic activity control.

Figure 1.3 Map of the location of the OIRFP "Prirazlomnoye"

The history of the development of the territories of the Pechora Sea had its origin in the XI century when Russian navigators began to develop the seas of the Arctic Ocean. The Great Northern Expedition described the Arctic coast and compiled maps in 1733-1742, after which, in 1898, the world's first Arctic icebreaker Ermak was built, 39 years later, the world's first drifting polar station "North Pole-1" was launched, in 1972, the USSR marine Arctic exploration expedition began exploration for oil and gas offshore. Already in 2014, the first batch of oil was shipped from the Prirazlomnoye platform itself. Prirazlomnoye opened in 1989. Production at the field began in December 2013. In September 2014, a million barrel of oil was produced. In 2014, about 2.2 million barrels of oil (about 300 thousand tons) were produced at

Prirazlomnoye. In November 2015, the field produced a million ton of the first Russian Arctic oil. The life of the field is at least 25 years. The project provides for the commissioning of 32 wells, including 19 producing, 12 injections and one absorbing. The platform costs about $800 million [3].

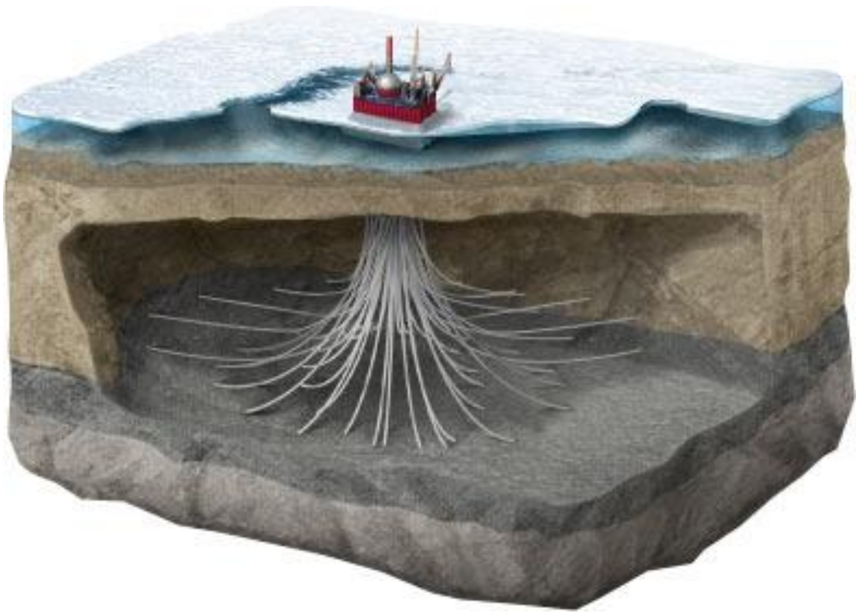

Figure 1.4 Illustration of the OIRFP “Prirazlomnoye” [4]

Oil recovered at the Prirazlomnoye field was named Arctic Oil (ARCO). New grade oil - ARCO has a distinctive feature, such as a high density (about 910 kg/m3), a particularly increased sulfur content, as well as a low paraffin content. ARCO is considered relatively heavy when compared with the usual Russian export oil. The oil recovered at Prirazlomnoye is the best for deep processing in the factories of northwestern Europe. It produces unique chemical products that can be used in road construction, tire production, in space and pharmaceutical industries [3].

Table 1.1 Technical characteristics of the Prirazlomnoye OIRFP [3]

Staff		200 people
Mass	own	117 thousand tons
	including ballast	506 thousand tons
Dimensions (edit)	total height	141 m
	caisson height	24,3 m

	caisson at the bottom	126 x 126 m
	caisson at the top	102 x 102 m
Caisson tanks	storage tanks for commercial oil	12 pcs. (113 thousand m3)
Performance	oil production plan for 2017	2.6 million tons
	production peak (after 2020)	5 million tons per year
	oil shipment period (at maximum production level)	6 days
Autonomy	shift of watches	30 days
	replenishment of materials	60 days

1.3 THESIS STRUCTURE

The thesis includes four chapters in total. The following is a brief description of the content of each chapter.

Chapter 1.

This chapter explains the motivation behind the implementation of tracer systems. This chapter also provides general information regarding oil and gas offshore fields, directly about the Prirazlomnoye field.

Chapter 2.

The second chapter tells about tracer systems, namely their types, the general concept of tracer systems, the history of their development. Tracer systems got their main development in our country at the beginning of 1990, and this is what the third part of this chapter tells about.

Chapter 3.

This chapter discusses tracer systems in more detail. The relationship between tracer systems and multistage hydraulic fracturing is explained. The chapter clearly shows how tracer systems work and what materials are used in them.

Chapter 4.

This chapter presents a discussion. After selecting a device for research, chemical elements for tracer systems and testing, all data obtained during testing was processed. As a result of the study, a table was compiled with all the data regarding the inflow from the well. This proves that tracer systems can be used as the «smart bottomhole zone».

1.4 AIM AND SCOPE

This work aims to analyze the information obtained using tracer (indicator) studies at the Prirazlomnoye field in order to monitor the fluid flow profile in a multi-stage fractured well. This approach will help to increase the period of waterless oil production, and in the case of a water breakthrough, choose the correct measures to promptly eliminate this breakthrough.

The objectives of this work are:

1. Description of the natural and climatic features of the Pechora Sea;
2. Description of tracer studies of wells and reservoirs;
3. Review of the indicator research cycle;
4. Study of the features of tracer studies at the Prirazlomnoye field;
5. Analysis of the obtained data after laboratory tests;
6. Proposal of the further well operation recommendations.

2. TRACER (INDICATOR) RESEARCH

2.1 DEFENITION OF TRACERS

The tracer method is based on introducing a predetermined volume of labelled liquid into the control injection well, which is pushed to the control production wells by the displacing agent by the subsequent (after injection of the labelled substance) continuous water supply to the control injection well. Simultaneously, samples are taken from the wellhead of producing wells. The samples taken are analyzed in laboratory conditions to determine the presence of the indicator and its quantitative evaluation. Based on the analysis results, the curves of the indicator concentration change in the samples are plotted against the time elapsed since the start of the labelled liquid injection for each control production well. The type of these curves characterizes the filtration inhomogeneity of the studied section of the formation. No method of analysis and research makes it possible to thoroughly study the geological and technological heterogeneity of the well space. However, the tracer type of research allows you to study proper filtration flows, which is a direct consequence of filtration heterogeneity. By interpreting the obtained results of indicator research, you can qualitatively and quantitatively assess the distribution, nature and behavior of actual filtration flows and, accordingly, make an idea of the filtration heterogeneity of the researched object.

The indicator method is designed to study the inter-well space of the formation and control the process of oil displacement by injected water. Therefore, conducting indicator research does not require a change in the existing development system of the object under research.

Tracer research involves using any indicators that do not disturb the geochemical equilibrium of formation fluids and do not degrade the oil-removing properties of the injected water.

2.2 TASKS AND REQUIREMENTS OF TRACERS

The use of the tracer method of supervision over the development of oil and gas fields allows solving the following problems:

- determination of direction, speed and distribution of injected water in the productive volume of the formation;
- determination of the inhomogeneity of the formation along the strike;
- establishment of hydrodynamic communication by area, determination of interpolate flows, etc.

The simultaneous operation of several different indicators helps to increase the prospects of the control method and increase the number of tasks to be solved:

- sources of main water flooding of production wells;
- determine the zones of influence of various injection wells;
- study the dynamics of oil displacement with water, determine the efficiency of the displacement process;
- control efficiency of use of oil recovery increase technologies
- Qualitative evaluation of interval performance
- Quantification of inflow
- Localization of water breakthrough

Labelled substances for tracing liquids shall meet the following requirements:

- Dissolve well in the liquid that is labelled; filter together with traceable liquid;
- Ensure reliable determination of background concentrations, a wide range of changes in indicator content and measurement express using available equipment;
- Enable selective measurement of the indicator while using multiple indicators;
- Be environmentally friendly and not affect oil refining processes;
- Have a cost that ensures the cost-effectiveness of indicator research.

Scope of indicator analyses:

Indicator research can be carried out at any flooding system and a water cut of production wells more than 5%, regardless of the number of productive formations opened by perforation [4].

Tracer research technology as a whole is not due to the method of well operation and equipment, as well as the values of fluid flow rates, the viscosity of oil and water, gas factor. Therefore, tracer studies do not affect well operation modes in any way.

Indicator analyses can be carried out in fields where injection of chemical compounds into formations is used to increase oil displacement efficiency with water, provided that these compounds do not affect the properties of the used indicators and their determination procedure. Using modern technologies, tracing studies can be carried out at any well.

Conditions of applicability

The fundamental factor in carrying out the works is the technical serviceability of the wellhead equipment and the tightness of the tubing of the production string and the annulus.

2.3 HISTORY OF TRACER SYSTEMS DEVELOPMENT

In the late 50s and early 60s of the last century, the USSR began the widespread introduction of tracers into geological and oilfield practice.

Under the leadership of academician G.N. Flerov, the Institute of Petroleum of the USSR Academy of Sciences and GrozNII (SevKavNIPIoil) revealed the possibility of using the tritium hydrogen isotope as an effective filter flow tracer to solve geological and oil field problems.

In 1956, tritium was first used at the Oktyabrskoye field of the Chechen-Ingush Autonomous Soviet Socialist Republic [5].

In 1963, at the Society of Petroleum Engineers (SPE) annual conferences, K.B. Bischoff made a presentation: Theory of tracer flow from the University of Texas. Although the report describes in detail the basics of the flow of the tracer in a two-phase stream (water, oil) as a component of water, the possibility of applying the classical laws of hydromechanics to describe the filtration of the tracer is justified [5].

In 1965 and 1966, W.E. Brigham and D.E. Baldwin made presentations at the Society of Oil Engineers (SPE) conferences, respectively. Both works were devoted mainly to attempts to theoretically substantiate the behavior of the pumped tracer in a five-point well layout (1 injection and four production wells). And D.E. Baldwin and W.E. Brigham were members of the American Institute of Mining Engineers (AIME), so the second work was a theoretical consequence of the first [5].

In the 70s, creative teams of Soviet scientists of various research and production institutes: VNIIYAG, gave and introduced technology for studying the filtration heterogeneity of the oil bed using a tritium tracer in the main oil producing regions of the country. In the same years, the active use of tritium began to control the development of oil fields [5].

In the early 70s, the possibility of using iodine-131 for short-term indicator studies was established.

Until the mid-80s, the radioactive isotope of hydrogen, tritium, was mainly used for tracer research as the most suitable (at that time) for technological and economic reasons compared to other tracers (strict movement with a hydrodynamic carrier, practically not sorbed by rocks, etc.).

A significant drawback of radioactive isotopes was their biological danger. Therefore, in parallel with tritium and further scientific research and practical work, the search for non-radioactive indicators (stable substances) was carried out. As a result, highly dispersed suspensions of brightly fluorescent materials (fluorescein, uraninite, rhodonite, etc.) have been widely used. The advantages of such indicators include their insolubility in the test medium; non-toxicity; resistance to physical, chemical and biological factors; sanitary and environmental safety and ability to be determined in any media, especially since studies (indicator injection and sampling) could (and can) be carried out not only by research but also by drilling, geological exploration and oil-producing enterprises.

In 1988, at VNIIgeoinformsystems (VNIIgeosystems) under M.S. Khostinov, as a result of research work, methodological recommendations were developed for determining filtration parameters of the inter-well space of oil deposits, based on the results of interpretation of studies conducted with tritium-marked water. The TRITIY program was also written for computer modelling of the process of quasi-uniform two-phase filtration of water, oil and fringing of labelled liquid for layered inhomogeneous reservoir formations. The paper proposes a refinement of layered non-uniformity of the formation by solving the inverse problem: to build a layered model of the formation according to the curve of labelled water concentration measured in production wells. An iterative approach was developed to construct a layered non-homogeneous model of the formation section for a pair of (injection and production) wells by comparing the calculated (built during the simulation of filtration of water, oil and tritium-marked water fringing) and the experimental dependencies of the curves "indicator concentration-time” [5].

A year later (in 1989), a guidance document was created: A methodological guide to the technology of conducting tracer studies and interpreting their results for regulating and controlling the flooding of oil deposits.

This methodological guide was a kind of integration of the accumulated knowledge in the field of indicator research of scientists from almost the country.

From the beginning of the 90s until today, no more recommendations were created in our country, and no new theoretical searches were carried out in the field of indicator studies of filtration flows in the inter-well space of oil fields.

In general, there are several drawbacks of the most acceptable indicators for oil field practice: the inability to register them directly in the stream, which makes it necessary to collect and transport samples and makes it difficult to introduce tracer studies in oil fields widely.

Successful resolution of this issue will make it possible to expand the possibilities of using indicator studies and introduce them into the category of standard methods in prospecting and exploration in the study, regulation and control of oil field development.

3. TRACER (INDICATOR) STUDIES IN MSHF USING TRACER PROPPANT

Multi-stage hydraulic fracturing (MSHF) is the most frequent method of intensifying oil production in many countries. When applying MSHF at a field, it is important to subjectively evaluate the effectiveness of this method on horizontal sections of wells, to record the work of each stage, including water cut, to timely create a plan for geological and technical work to localize the water breakthrough into the well from a certain interval [2]. Tracer studies solve expensive geophysical work on horizontal wells, associated with quite time-consuming lifting operations in the wellbore of various geophysical equipment. Tracer studies in multi-stage hydraulic fracturing are carried out by introducing a specially labelled proppant during the formation of cracks or by injecting a gel with dissolved labelled particles. After starting the well, the fluid begins to filter in the injected proppant and carry the indicator particles to the surface. Today, a huge number of labelled substances (tracers) are used. Indicator studies allow us to solve several problems, such as determining the direction of crack development during hydraulic fracturing, monitoring the inflow in the intervals of perforation of a horizontal well, and registering the growth of product water cut and localization of water break in a certain stage. The technology of conducting indicator studies with the injection of labelled proppant allows you to obtain accurate information for several years in the operating modes of the well without stopping production, with minimal cash investment for the purchase of proppant during hydraulic fracturing. Figure 4.1 shows a well with a hydraulic fracturing operation [3].

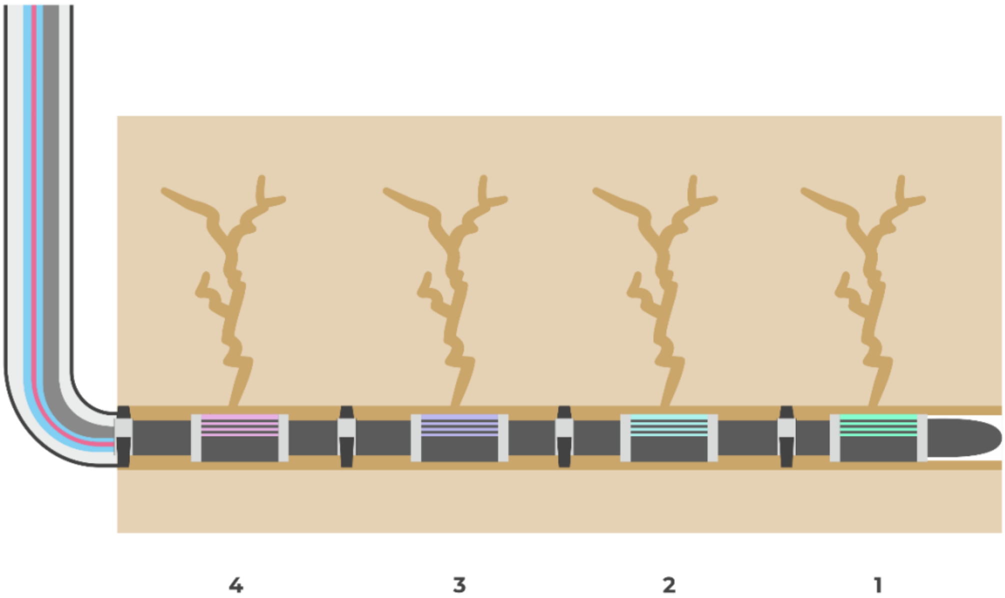

Figure 3.1 Hydraulic fracturing at the well

3.1 TRACER GEL INJECTION

When a special gel is injected, it fills the cracks and is carried out for several months together with the extracted liquid to the surface, where samples are then taken and analyzed (Figure 3.1).

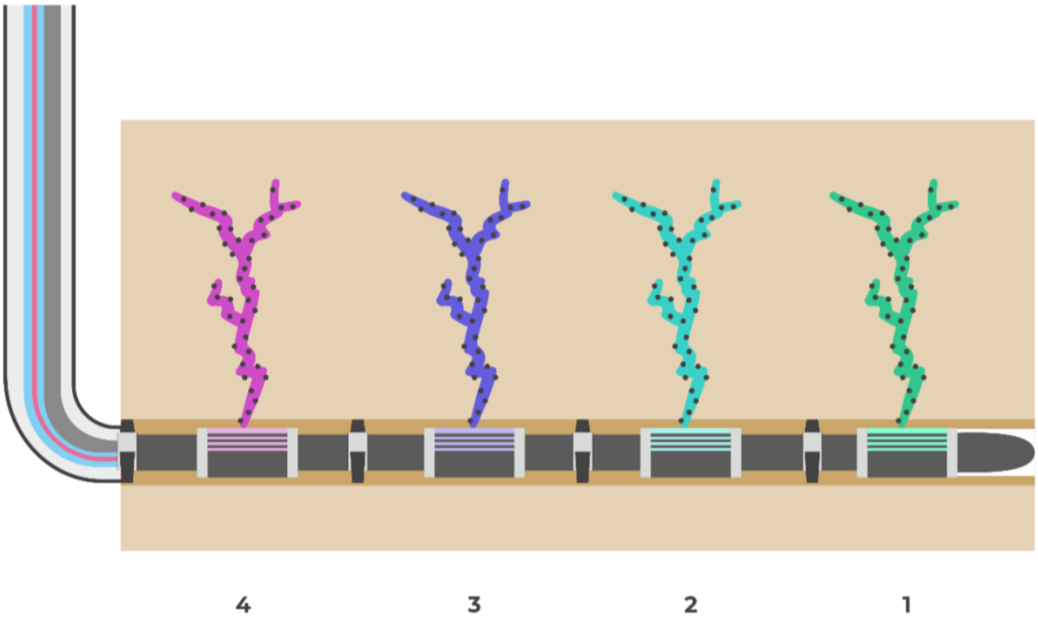

Figure 3.2 Filling cracks with indicator gel

Figure 3.3 shows a more detailed picture of a crack with a labelled gel.

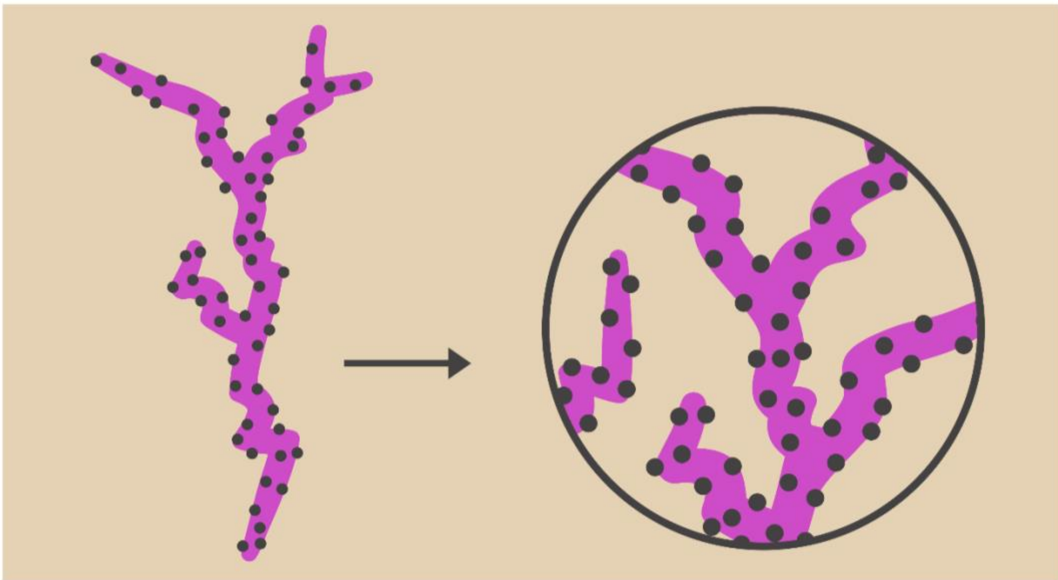

Figure 3.3 Image of a crack filled with indicator gel

3.2 TRACER PROPANT INJECTION

Similarly, studies are carried out with tracer proppant. Only the already labelled particles are sewn in the proppant and released into the target fluid when filtered with it. Figure 3.4 shows a well with labelled proppant.

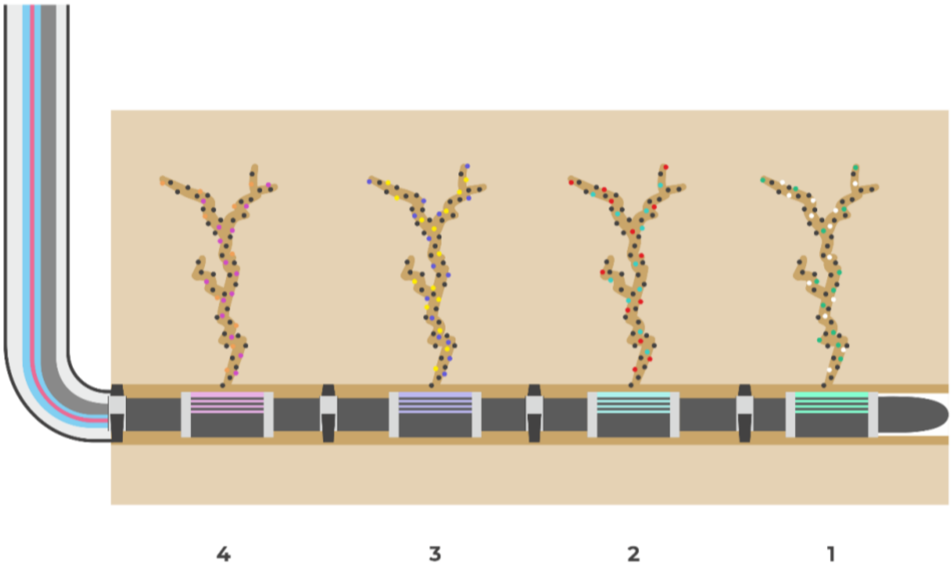

Figure 3.4 Well with embedded labelled proppant for water and oil

With this method, it is possible to pump proppant with different tracer particles into one crack, which will allow determining the flow rate of each phase in the liquid flow from one perforation interval. For example, in Figure 3.5, you can see that you can see blue and pink proppant mixed with ordinary proppant. One dissolves in the water phase, the second in the oil phase.

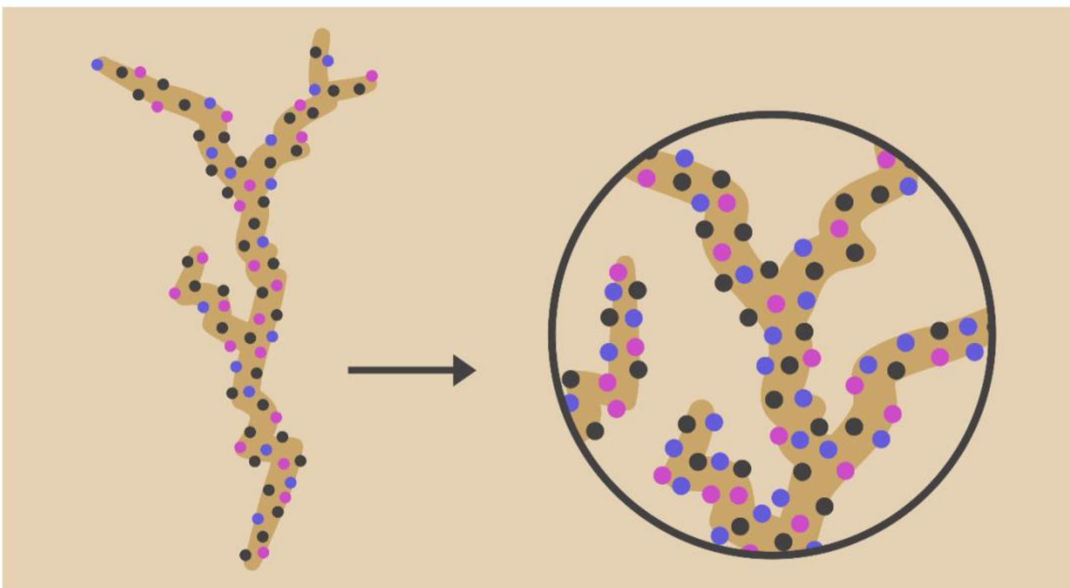

Figure 3.5 Crack of the 4th tailgate with indicator proppant

This technology can be used not only on horizontal wells but also on conventional wells where hydraulic fracturing is performed. The use of tracer technology in MSHF allows you to solve a huge number of problems:

- Evaluate the flow profile of downhole production after hydraulic fracturing
- Evaluate the individual contribution of each water and oil interval to the overall well flow rate
- Conduct research and analysis of potential long-term hydrocarbon recovery
- Evaluate and analyze the influence of neighboring stages on each other and the mutual influence of neighboring wells.

3.3 TRACER MATERIAL VARIETY

The theoretical basis of the method is molecular diffusion, which characterizes the movement and mixing of reservoir fluids with introduced tracer particles. Since the permeability of the cracks is significantly higher than the permeability of the rock, the fluid flows precisely through the cracks where the labelled particles are located. The physical principle of tracer methods involves the long-term leaching of indicator particles from cracks, which are unique for each hydraulic fracturing stage. Tracer proppant is a chemically resistant, solid polymer ball containing phosphor molecules. The diameter of this ball is 1 micron. For tracer studies, water-soluble and oil-soluble chemical reagents are used, which are not sorbed or minimally sorbed by the rock. Therefore, tracers must have the selective ability to penetrate only the target fluid, their hydrodynamic carrier [2].

Water-soluble tracers are divided into two groups: Ionic and fluorescent:

- Ionic:
  - Sodium nitrate, ammonium;
  - Ammonium rhodanide, sodium;

    - Disodium Phosphate
    - Urea;
    - Thiocarbamide.
- Fluorescent
    - Disodium salt of eosin;
    - Sodium fluorescein.

Oil-soluble tracers:

- Methylpropanol-1;
- Butanol-1.

The principle of a quantitative and qualitative study of the composition of extracted fluids is as follows: there are four pairs of different colours, the same for both water and oil, which, when washed out of the crack, are fixed to the target phase, so a liquid flow with a different set of tracer molecules is formed at the wellhead. The possibility of using the same indicators for water and oil is that the molecule, falling into one of the phases (water or oil) of a multiphase system, does not leave it since it cannot overcome the phase boundary. The low mass of the tracer provides this. Using this method, you can also calculate the inflow from each stage of a vertical or horizontal well during the MSHF. To obtain data on the inflow of each section, the share in the total number of indicators for each fluid is calculated separately. The resulting fraction directly reflects the proportion of a particular fluid from a particular crack or section, and hence the flow rate of each interval for the fluid of interest. In such a study, luminescent microscopy is used according to a special technique. The limitations of this technique are that the number of stages cannot exceed five, and the reservoir temperature cannot exceed 130 °C [5]. Let's consider an example of conducting such studies on wells that meet these criteria. In the final stages of multi-stage hydraulic fracturing, up to 15 tons of labelled particles are injected in the form of a proppant coated with a fluorescent, non-radioactive, soluble polymer. Immediately after starting the well, samples are taken at a certain time interval between each sampling and all samples are sent for laboratory analysis. The accuracy of tracer diagnostics is ±1%. As a result of diagnostics, it is possible to determine the fluid inflows of each stage. This method of reservoir indicator study is "stationary"; that is, it is carried out in the operating mode of the well and does not require stopping or other expensive geological and technical measures. In this case, the following filtration-capacitance characteristics of the collector section are determined:

- Well flow rate
- Rock volume
- Oil recovery factor

When using the static source method in the conditions of a well with MSHF, along with the above parameters, the quantitative contribution of each perforated interval to the total flow rate of the liquid is determined (Figure 3.6).

Figure 3.6 Position of the marked water flow lines in the near-well space [6]

For the most accurate determination of the reservoir parameters as a result of the indicator study of the well, it is necessary to pay sufficient attention to the following main quantitative parameters of the indicator fluid:

- The optimal volume of tracer fluid is determined by the geological characteristics of the well and is from 5 to 8 m3 of solution;
- The period of diffusion transfer is from 0.5 to 5 days;

- The concentration of the tracer should be in the range of 2 to 125 grams per litre in the volume of injected water and depends on the brand of the tracer.
- The sampling period is required to provide the most reliable data on the work of each section and lasts from 30 to 40 days.

Table 3.1 shows an example of the initial data of the tracer study of wells required to interpret the results.

Table 3.1 Example of the initial data of the tracer study when the tracer is injected into the fractures of the hydraulic fracturing

HF Stage	Planned number of ports, m	Tracer	Injection mass, kg	The volume of tracer fluid, m^3	Date
I	Port 1 (4157 m)	Sodium Thiocyanate	500	5	08.09
II	Port 2 (4035 m)	Urea	1000	8	08.09
III	Port 3 (3845 m)	Fluorescein	20	5	09.09
IV	Port 4 (3720 m)	Thiocarbamide	1000	7	09.09

Fluorescent tracers belong to the group of phosphors, the method of their determination in the selected samples is to measure the luminescence of the solution in a given wavelength range. Use the device "Fluorat-02 Panorama", which can detect the current concentration of the tracer in the test sample. The verification of each measurement is performed on special software and is as accurate as possible.

For the study of ion tracers, a photo colorimeter "KFK-5M" is used, which measures the optical density of solutions obtained due to the photo colorimetric reaction of the selected sample.

To study oil-soluble tracers, it is necessary to prepare samples so that the marker is selectively extracted from the oil. Then, the marker is concentrated for gas chromatographic analysis with a given detection sensitivity. For the analysis, gas-liquid chromatography is used: "Crystal" and " Tsvetyauza».

We use observations of changes in the tracer concentration in fractured fractures using the "Stationary" method of investigation to interpret the results. After that, we write a conclusion about the intensity of the liquid flow at each stage separately and model the trend components that characterize the shape of the tracer outflow. Next, a comparison with the actual graphs is made, and conclusions are drawn on the operation of each interval of the well. Finally, the results of the interpretation of the indicator study are filled in in the table. When analyzing the results, you can see that with an increase in the flow from a certain crack, the intensity of the tracer removal increases. In addition, an increase in the particle mass indicates an increase in the mass fraction of the tracer penetration into the target fluid flow.

The period of sampling at the well after the process of hydraulic fracturing and injection of tracer molecules:

Table 3.2 Sampling time and period

Day	Sampling time
First 3 days	3 times per day
3–8 days	1 time per day
8–30 days	1 time per 2 days
More 30 days	1 time per month

Table 3.3 shows examples of the results of interpretation of tracer studies.

By the mass of the tracer removed, can be determined:

- Inflows in the hydraulic fracturing interval;
- Determine the water content, as well as identify the trend of water content;

Plot the graphs of measurement indicators to diagnose further water cut.

Table 3.3 Interpretation of the results obtained

Stage of HF	Tailcoat port, m	Mass of the washed tracer, kg	The number of the injected indicator, kg	The volume of channels replaced by labelled liquid, m^3	Calculated coefficient of extraction of labelled liquid, pcs.	The value of the specific surface of the channel volume, m^{2}/m^{2}	Conditional performance of the tailgate, m^3/day
I	Port 1 (4157 m)	252,4	500	3079	0,10	131465	106
II	Port 2 (4035 m)	403,3	1000	9821	0,20	153920	340
III	Port 3 (3845 m)	1,7	20	1029	0,01	17737	36
IV	Port 4 (3720 m)	110,2	1000	1150,9	0,09	15361	46
Oil density 0,821 kg/m^3							

4. DISCUSSIONS ON TRACER STUDIES AT THE PRIRAZLOMNOYE FIELD

4.1 TRACER STUDY DESCRIPTION

In the Prirazlomnoye field, the most modern method of well tracer studies is used. Its peculiarity is that it can be carried out for 5-10 years and the cost of the technology is much lower, in contrast to the proppant method. The technology of this method consists of the use of special polymer rods with embedded unique tracer molecules, which, upon contact with the target fluid, begin to emit tracer particles (as in the proppant method). Still, the rods are installed in the downhole equipment in the perforation intervals. The number of unique tracer molecules can reach 100 pieces for both water and oil. Respectively, this method does not limit the number of studied stages of hydraulic fracturing. Since tracers are unique, polymer rods can be installed at each perforation interval in horizontal wells during multi-stage hydraulic fracturing. The rate of release of tracer molecules is constant after the first contact with the target fluid and does not depend on the rate of flow washing the rod. Tracer indicators are selected individually for certain well parameters, such as:

- Temperature;
- Maximum flow rate at the sampling point;
- Required service life.

Tracer studies with polymer rods can be carried out both in the transient operation mode of the well and in the steady-state operation mode.

During the transition mode of operation of the well, production is stopped for a certain time, and then the well is started again. In this mode, you can define:

- Monitoring of well cleaning;
- Assessment of the distribution of fluid inflow by zones;
- Hydrodynamic coupling between fluid zones/flows.

When the well is in steady operation mode, there is no need to stop production. That is, the well is operating normally. In this mode, you can:

- Identify the source of flooding;

- Perform long-term monitoring of downhole production.

The peculiarity of this system is that it is possible to constantly monitor and monitor the performance of each well interval for many years. Thus, it is possible to track the dynamics of the productivity of each zone, perform timely geological and technical work and make objective decisions on the productivity of the well.

Another useful property of tracer rods is that they are in "sleep mode" without contact with the target fluid and do not emit any indicator molecules. The service life of the tracer rods begins from the moment of contact with the target fluid. During the "sleep mode", the tracer rods are not consumed and can stay longer in the wellbore. Also, using this property, you can determine the breakthrough of water into the well from a certain interval, provided that in each interval, there are two types of rods (for water and oil). With regular sampling, it is possible to determine the increase in water content on time and plan the necessary geological and technical measures at the wellhead without conducting additional and costly geophysical studies.

The project cycle of tracer studies consists of six stages, shown in Figure 5.1, where sampling and analysis are looped together.

Figure 4.1 Project cycle of tracer studies

At the first stage, the design of the indicator study is selected for certain parameters of the field and downhole equipment. Then, tracer rods of a certain size with unique molecules sewn for each interval and a specific fluid (water or oil) is started.

At the second stage, the tracer rods are integrated into the wellhead completion equipment. Then, they are installed in sand filters, through which the entire volume of liquid extracted from the field passes.

The third stage is the descent of the tubing string into the well with the installed rods for water and oil.

The fourth stage is sampling at a certain time interval, which increases over time.

The last stage is the analysis of the samples obtained and the subsequent interpretation of the data obtained.

Sampling, analysis, and interpretation occur throughout the life of the indicator rods.

The sampling program for each model is developed individually based on the initial data about the well.

There are 3 sampling periods in the transient operation mode:

1. Cleaning and early production period samples are taken as often as possible with a time interval of half an hour and eventually increasing to several hours per day. During this period, there is a qualitative assessment of the cleaning and operation of the horizontal well intervals after hydraulic fracturing.
2. Stopping and resuming production samples are taken quite often at intervals of five minutes to an hour for a couple of days. During this period, a quantitative assessment of the fluid inflow profile from the reservoir is observed.
3. Stationary mode-Samples are taken weekly. During this period, a qualitative assessment of the intervals is observed, and the well is examined for the presence of water breaks for their rapid localization.

4.2 DEVICES DESCRIPTION

When using fluorescent tracers, the research method is based on measuring the luminescence of a solution at a certain wavelength range.

For research, a special device is used that determines the concentration of the indicator "Fluorat-02 Panorama". It is connected to a personal computer and activated by special software.

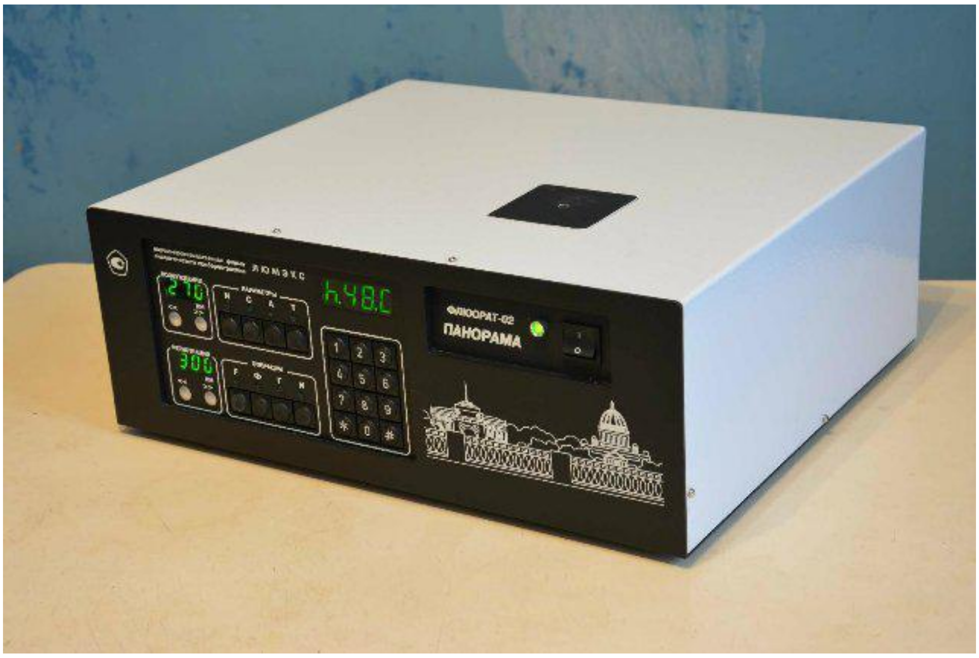

Figure 4.2 "Fluorat-02 Panorama" research spectrum fluorimeter [7]

Ion tracers are composed of crystalline colorless inorganic substances. When using ion tracers, the optical density of the solution obtained due to the photo colorimetric reaction of the selected sample from the well is measured.

For analysis, a photoelectric colorimeter of the "KFK-5M" type is used as an analyzer».

Figure 4.3 "KFK-5M" Photoelectric Colorimeter [7]

Organic tracers are crystalline, colorless substances and liquids. The method of measuring organic indicators is based on the determination of the area of the chromatographic peak when the substance is dosed into the evaporation column of the chromatograph by its delay time, as well as on the measurement of the optical density of the solutions obtained as a result of photo colorimetric reactions.

Gas and liquid chromatography of the "Crystal" and "Tsvetyauza" types are used for research».

Figure 4.4 Gas chromatograph «Crystal-5000» [7]

Figure 4.5 Liquid chromatograph "Tsvetyauza» [7]

4.3 SAMPLE SELECTION

To obtain a high-quality result on the removal of the indicator, it is necessary to prepare samples. There are two ways to clean samples from possible colloidal impurities:

- Mechanical method samples are subjected to centrifugation at a frequency of 12,000 rpm or more.
- Chemical method-a special technique using chloroform is used.

Since the rate of release of tracer molecules is constant and does not depend on the rate of flow washing the tracer rod, when the well is stopped, a "cloud" of a high concentration of indicator molecules forms around the tracer rods, at all intervals. (Figure 4.6, 4.7)

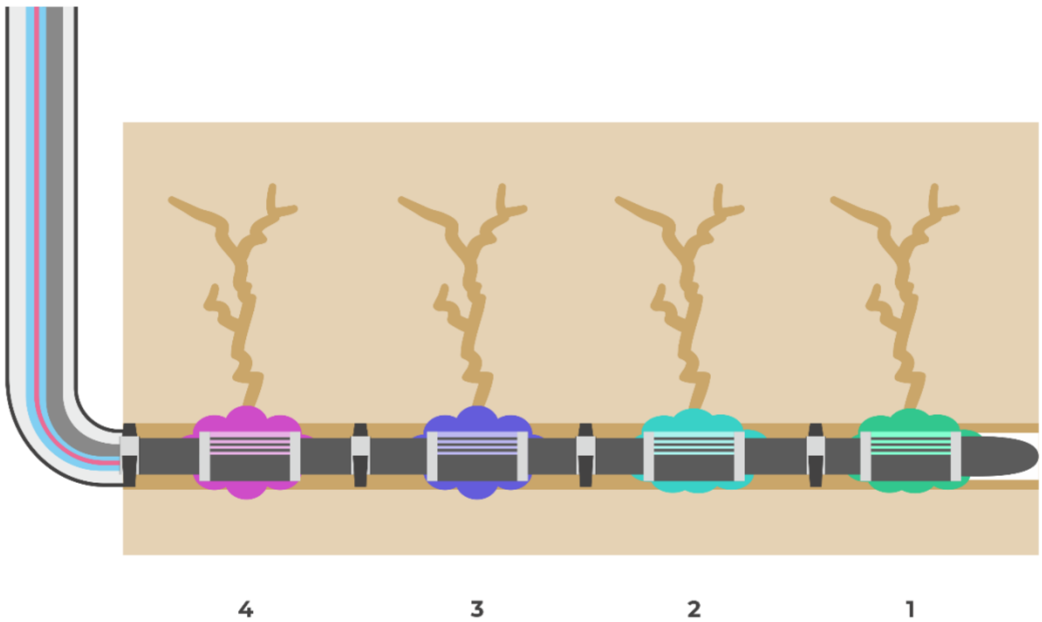

Figure 4.6 Clouds of tracer molecules

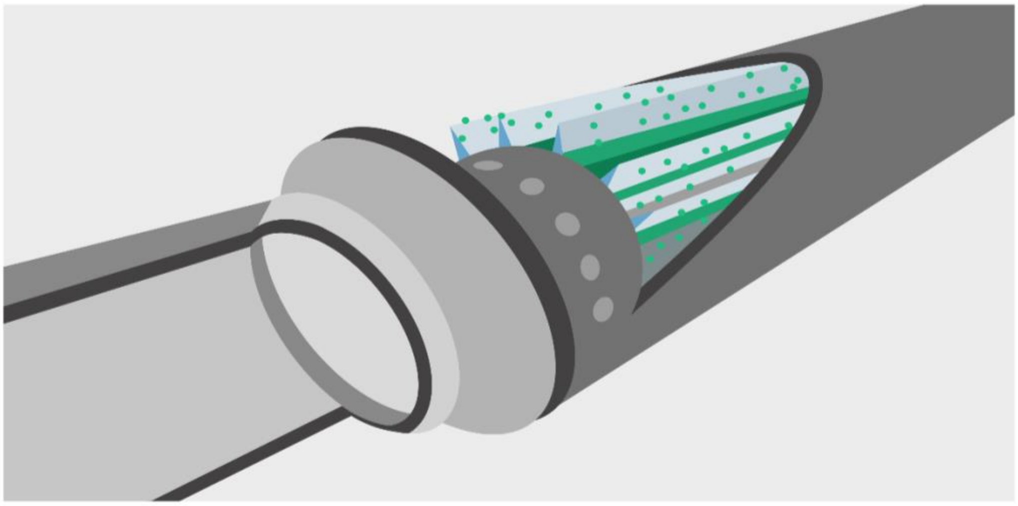

Figure 4.7 Extraction of labelled molecules by tracer rods

When starting a well (resuming production), the" clouds " of molecules move towards the mouth, where samples are subsequently taken at a certain time interval (Figure 4.8, 4.9).

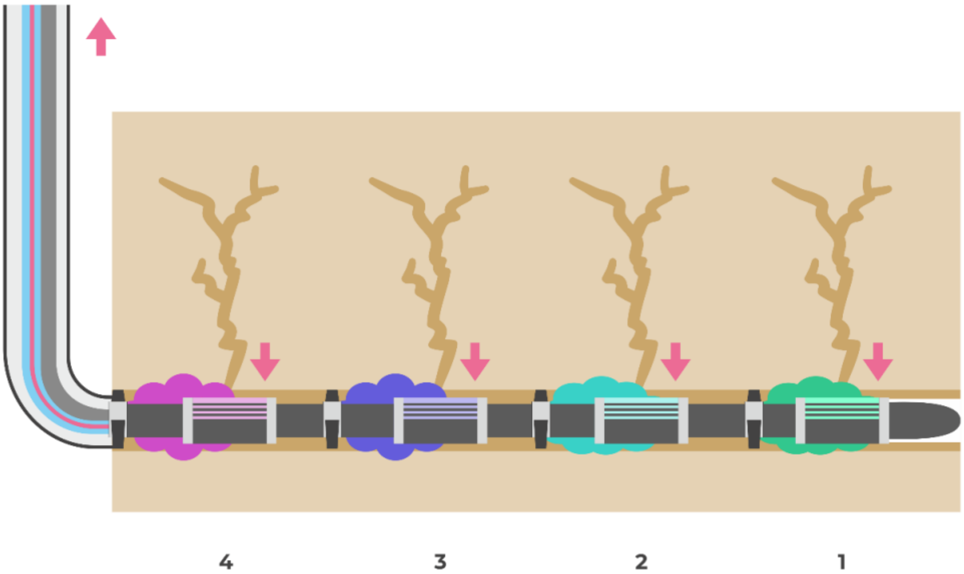

Figure 4.8 Tracer cloud shift.

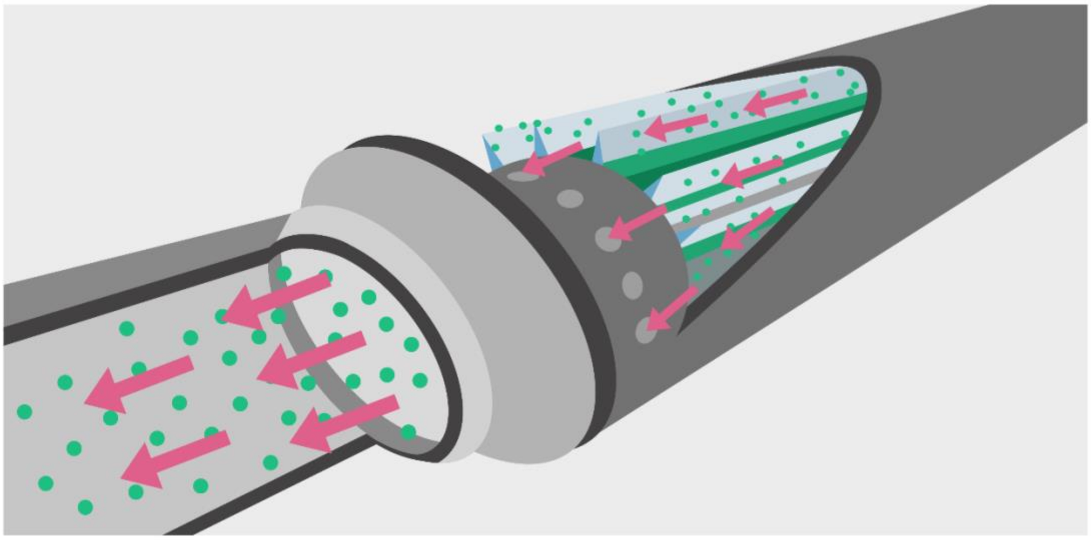

Figure 4.9 Movement of tracer molecules after starting the well along with the tubing

4.4 RESULTS INTEPRETAION

After sampling, the chemical analysis of the samples is carried out in a special laboratory. The result of the analysis is discrete responses from tracers. According to the conclusions of the chemical analysis, it is possible to determine the operating intervals, the flow rate of each interval for a certain fluid (water or oil), and change the oil production strategy. (Figure 4.10, 4.11)

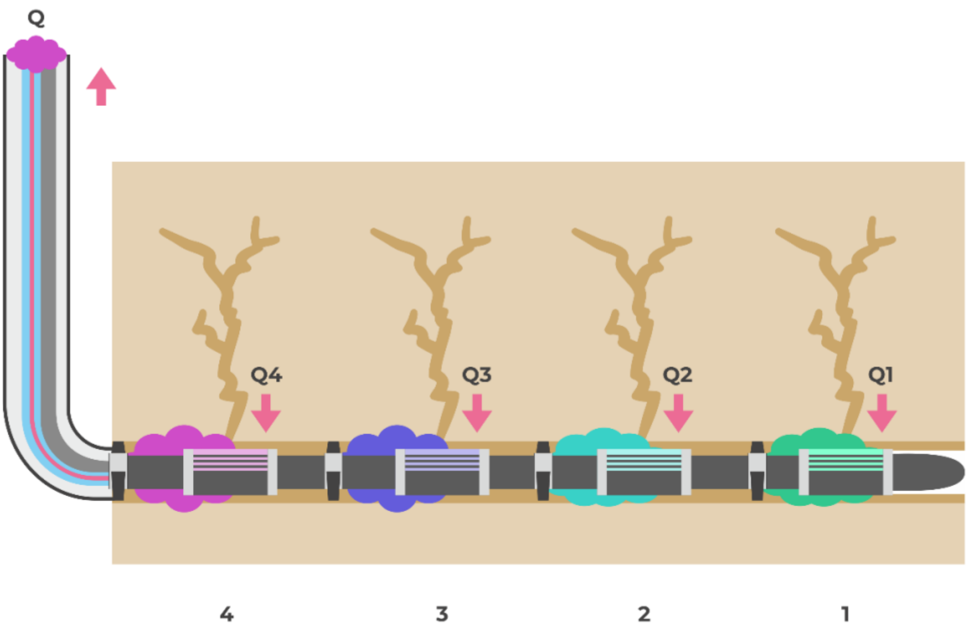

Figure 4.10 Sampling at the wellhead

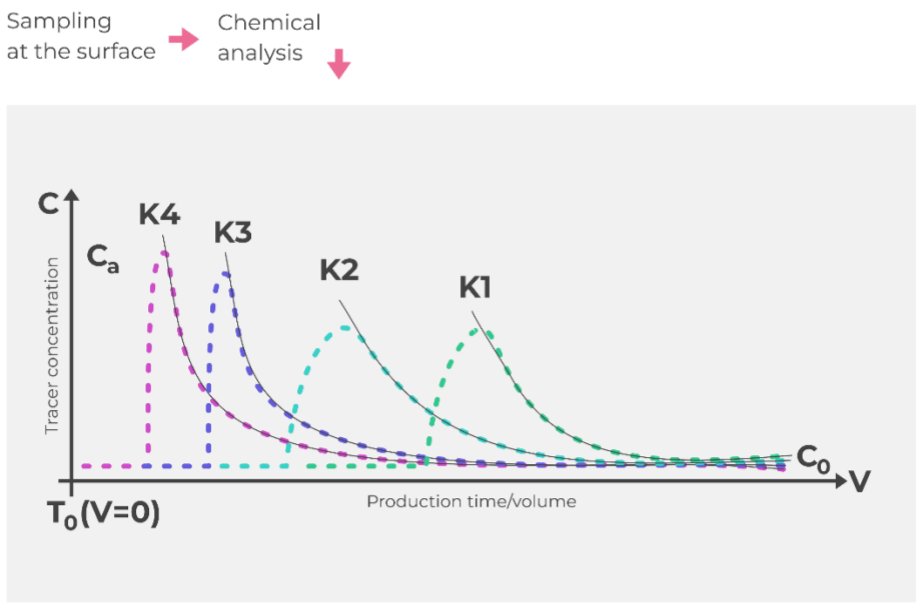

Figure 4.11 Discrete tracer responses

The presence makes a qualitative assessment of the intervals of responses from indicator molecules that confirm the inflow from a certain interval of perforation. The absence of characteristic peaks or a violation of the order of their arrival in the transition mode signals the presence of overflows in the well. Using the signal form, it is possible to qualitatively evaluate the operation of the intervals (Figure 4.12, 4.13.)

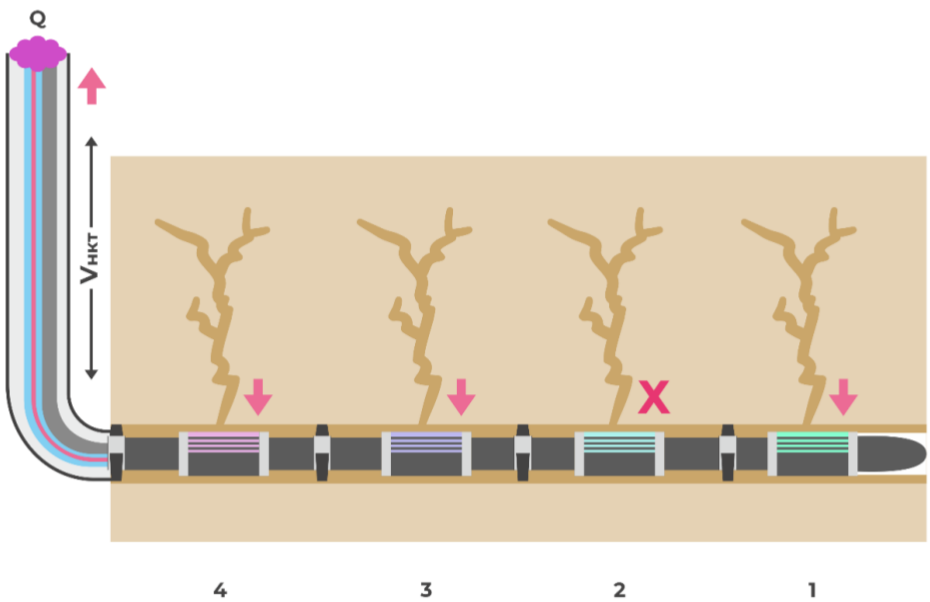

Figure 4.12 Qualitative assessment of the work of intervals

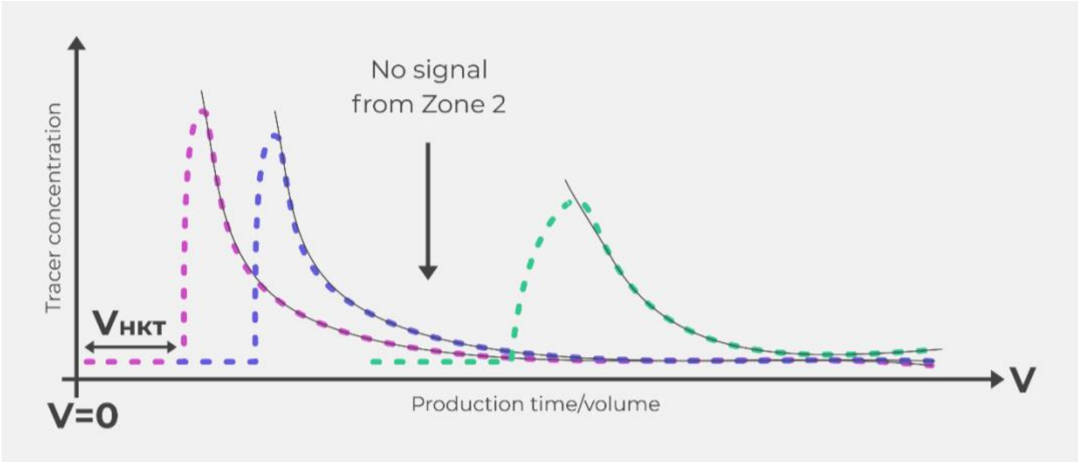

Figure 4.13 Discrete tracer response

After the chemical analysis in Figure 4.13, there is no peak on the tracer curve from the second blue zone. This may mean that tracer particles are not washed out of this zone, and, accordingly, the target fluid is not extracted.

Quantitative assessment of the inflow. The rate of leaching of the tracer "cloud" from the carrier depends on the inflow to the vicinity of the carrier and is determined by the coefficient k of the tracer concentration decline curve: $C = C0 + CAe - kV$

$Q = Q_1 + Q_2 + Q_3 + Q_4 = 100\%$

$Q_4 = 60\%$

$Q_3 = 15\%$

$Q_2 = 20\%$

$Q_1 = 5\%$

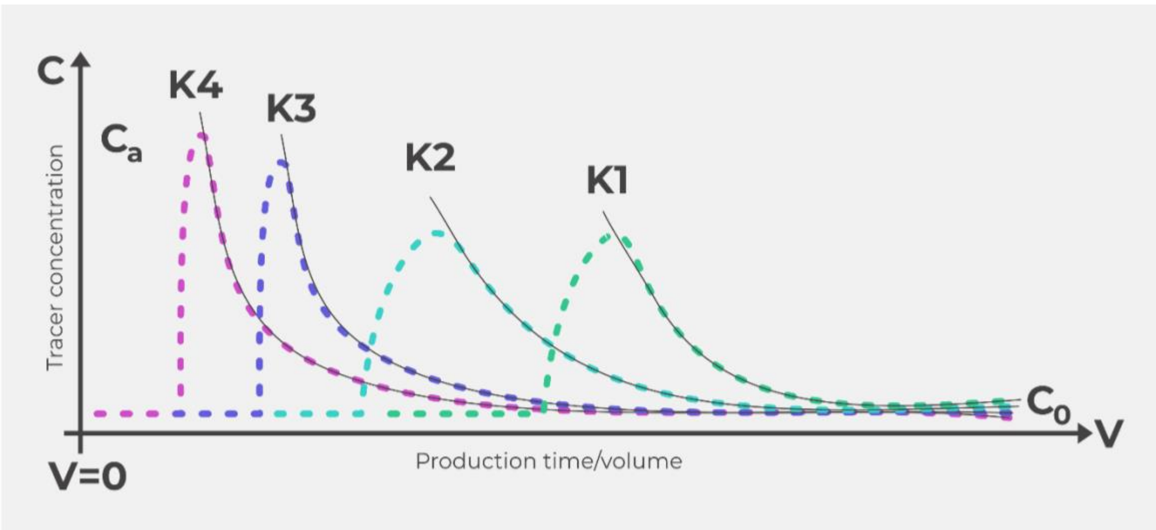

Figure 4.14 Tracer concentration decline curve.

At the Prirazlomnoye field, the "Flushout" technology will be used in the transition mode of well operation. The well is pseudo-intelligent. Its length is 4123 meters. At the tail of the well, 6 behind-the-well hydraulic packers separate six perforation intervals. Valves with inflow control devices and discharge valves are installed at all intervals. The discharge valves are adapted for carrying out hydrochloric acid treatments. If a water breakthrough in the well at a certain interval, it is possible to close a specific valve at this interval using a special tool on the tubing or tubing. Thus, in the Prirazlomnoye field, using such a well completion technology, the concept of a pseudo-intelligent well is implemented when it is possible to regulate the work with the help of small interventions. To implement this methodology, it is necessary to understand how each interval works throughout the life of the well and determine the intervals of water breakthrough. This is implemented using the technology of intelligent inflow indicators.

Unique indicator polymer rods of rectangular cross-section with a length of 1100 mm, a width of 6 mm and a height of 3 mm were installed in the wellhead equipment.

- Operating temperature of the well 58 °C;
- Ability to pump saline solution for stimulation;
- Oil density: 851 kg/m^3 (25,7° API)
- Maximum flow rate at the mixing point (O/W/G): 2000 m^3/day

In each interval, 100 pairs of tracer rods for water and oil are installed (RES OIL + RES H2O), 100 identical indicators for water and 100 indicators for oil, which are distributed between two inflow control devices. Thus, in each interval, a pair of unique tracer systems were located, which were conventionally designated as follows:

- OS — oil marking system;
- WS —watermarking system.

Figure 4.15 Integration of tracers into finishing equipment [8]

Service life:

- RES OIL: minimum 5 years
- RES H2O: minimum 1 year
- Tpacc Tracers are inactive when there is no contact with the target fluid, that is, they are in "Sleep mode».

The numbering of the intervals begins with the bottomhole from 1 to 6. An individual colour indicates each interval.

- The first interval is light purple;
- The second interval is green;
- The third interval is pink;
- The fourth interval is blue;
- The fifth interval is green;
- The sixth interval is purple.

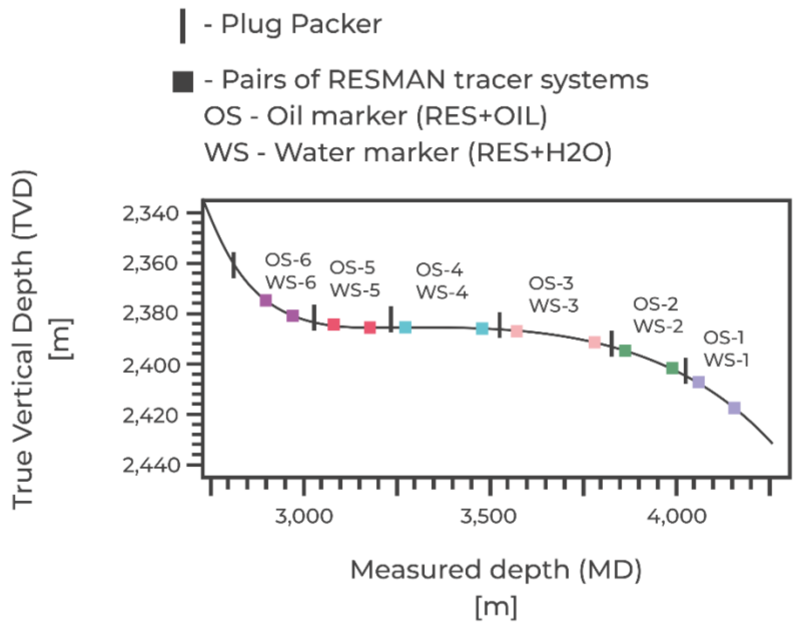

Figure 4.16 Intervals of perforation and installation of tracer rods

Section of the permeability cube along the well path.

Table 4.1 Borehole permeability

Interval	6	5	4	3	2	1
Depth	2915–3068 m	3073–3256 m	3262–3525 m	3530–3805 m	3810–3993 m	3999–4123 m
Average permeability	44 mD	75 mD	113 mD	122 mD	105 mD	58 mD

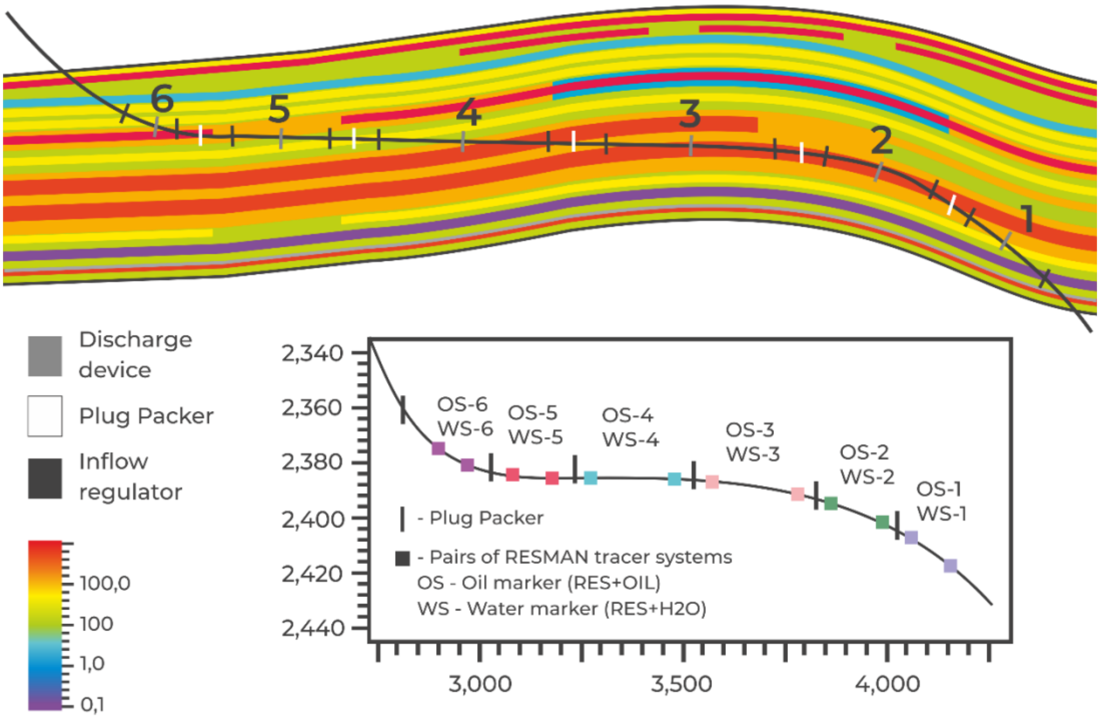

Figure 4.17 Borehole permeability section

After the well was stopped, a 10-day pause was issued. Before the static mode, 3 launches were made. There was an 80-minute pause between the 2nd and 3rd launches. The flow rates were as follows:

- First start: 2.35 m^3/h;
- Second start: 38.5–42.5 m^3/h;
- Third start: 48–61 m^3/h.

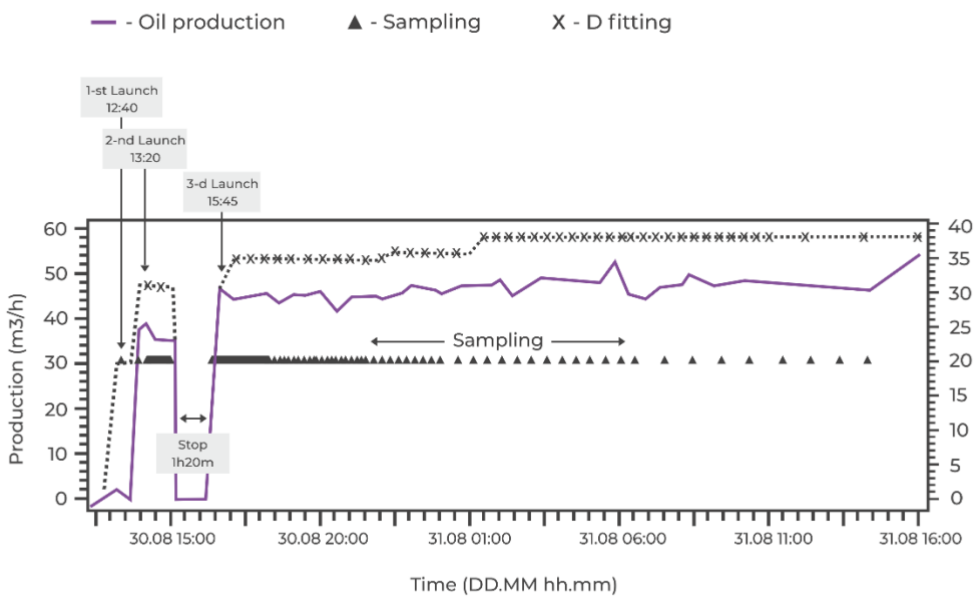

Figure 4.18 Sampling schedule

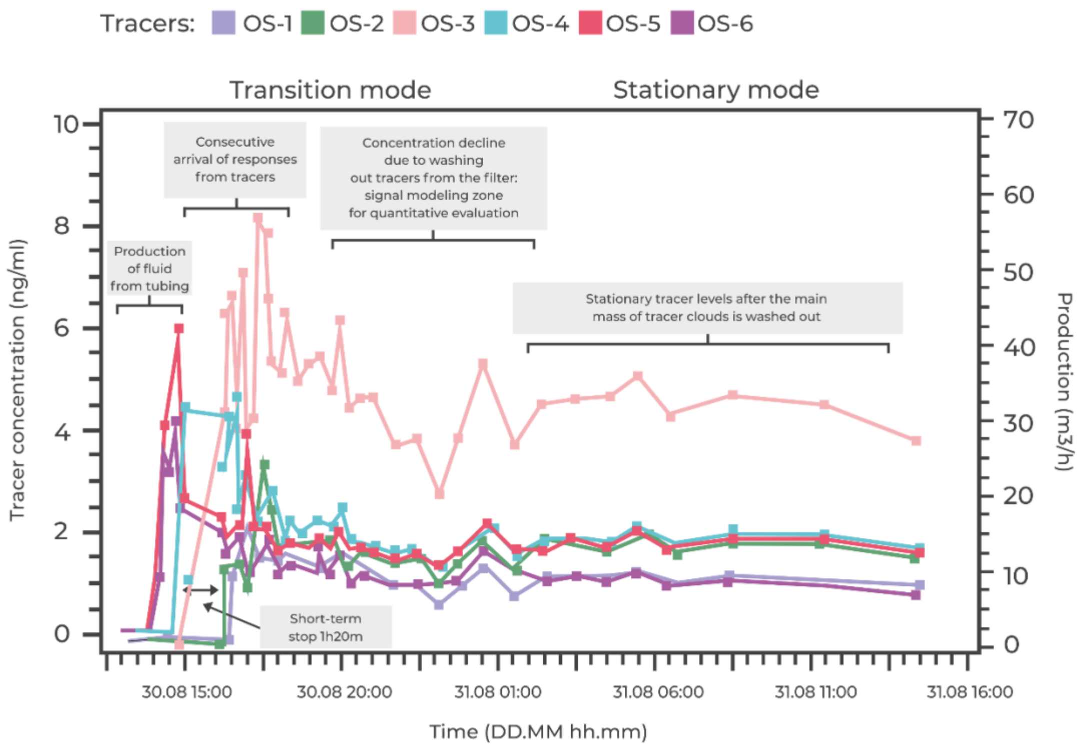

Figure 4.19 Tracer concentration graph

According to the graph in Figure 4.19, it can be determined that all intervals produce oil since there is a response from the tracer of each perforation interval. You can also use the graph to determine the 4 response periods of the tracer:

1. Production of fluid from tubing;
2. Sequential arrival of responses from tracers;
3. Decrease in concentrations due to leaching of tracers from the filter: signal modelling zone for quantitative estimation of inflow;
4. Stationary levels of tracers after washing out the main mass of indicator " Clouds».

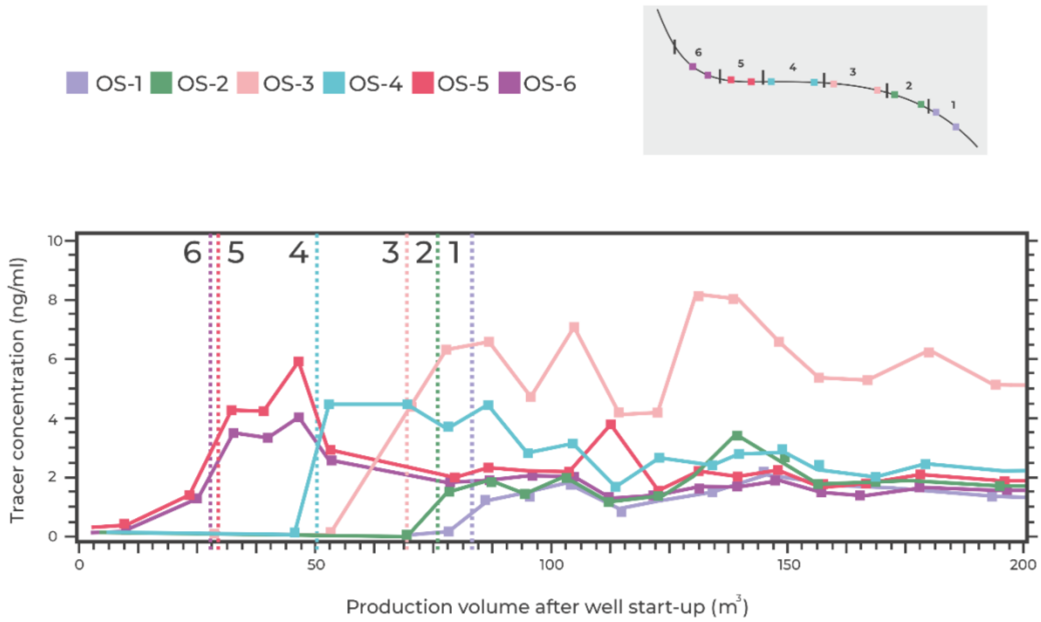

Figure 4.20 Tracer concentration graph

According to the tracer response graph in Figure 4.20, you can determine the sequence of response intervals. The graph shows that the tracers are registered in the same order as they are located in the well. This indicates that there is no significant fluid flows in the reservoir.

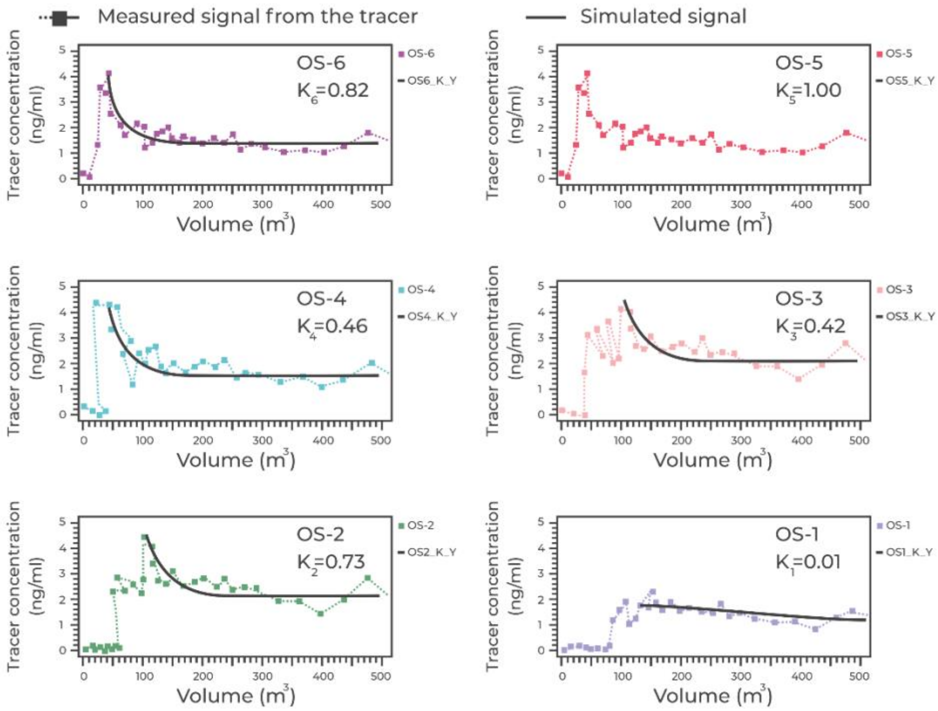

Figure 4.21 Graphs of the ratio of the measured and modelled signal

The graphs determine the key parameter K - the coefficient of the decline of the concentration curve, which characterizes the productivity of the interval.

4.5 THE RESULTS OF TRACER STUDIES AT PRIRAZLOMNOYE OIL FIELD

The presence of oil responses from all tracer rods confirms the operation of all well intervals. However, there are no responses to the water rods, so there is no water in the well.

Since the initial appearance of each indicator particle corresponds to the order of the rods in the well, it can be judged that there are no fluid flows between the zones. As a result of the study, a numerical estimate of the inflow of fluid(oil) for each zone was determined:

- The maximum inflow is observed in zones 5, 6 and 2 (up to 72% of the total well flow rate);
- The lowest performance is shown by 1 zone (about 3%);
- The numerical estimation of the flow rate distribution over the intervals is relevant only for the operating mode of the well under which the study was performed. When changing the operating mode of the well, the flow rate distribution may change. In this case, it is necessary to re-conduct a similar study under the conditions of the new mode;

The distribution of inflows by intervals is shown in table 6.1.

Table 4.2 Distribution of inflow by well intervals

Interval	6	5	4	3	2	1
Depth	2315-3068 m	3073-3256 m	3262-3525 m	3530-3805 m	3810-3993 m	3999-4123 m
Average permeability	44 mD	75 mD	113 mD	122 mD	105 mD	58 mD
Productivity coefficient	0.82	1.00	0.46	0.42	0.73	0.01
Flowrate, %	23 %	28 %	13 %	12 %	21 %	3 %

Flowrate, m^3/h	11.5	14.0	6.5	6.0	10.5	1.5

Recommendations for working with the well:

- Conduct a well study according to the "Stop and start (transition mode)" program once a quarter to numerically estimate the fluid inflow at intervals and track the dynamics of the productivity of the intervals.
- To minimize the distortion of the tracer signals and improve the quality of the numerical estimation of the inflow distribution, observe, if possible, the following conditions:
  - Stop the well for no more than 24 hours;
  - Start-up of the well in the normal mode with the ESP;
  - Try to avoid multiple stop-starts of the well.
- The results of this study are relevant only for the operating mode of the well under which the study was conducted. Therefore, when changing the operating mode, it is necessary to re-perform the tracer study of the well.
- It is necessary to take weekly fluid samples in a static mode to monitor stationery products and rapid detection of potential water breakout. It is very important to take samples both after and before the occurrence of water breakthrough events to determine the breakthrough and localize the water breakthrough zone reliably.

5. CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

In this master's thesis, the possibilities of applying tracer studies at the Prirazlomnoye field were considered.

The general information about the field and the platform was studied. The geographic characteristics of the field, the features of oil production on the Arctic shelf and the technical characteristic of the Prirazlomnaya paltform were considered;

The history of the tracer studies development and tracer technologies, and the project cycle of research were studied.

The most suitable model of tracer studies for the Prirazlomnoye field was considered. The methodlogy for conducting tracer studies in the conditions of field considered, the description of necessary devices, the sampling process, as well as the interpretation of the results obtained were studied in detail.

Recommendations for the further application of tracer systems at the Prirazlomnoye field were given.

5.2 FUTURE WORK

In this work a waterless oil production well is considered. The next stage of the work is to identify the moment of water breakthrough into the well. This requires a more precise interpretation of the sampling results in order to determine the breakthrough zone and the volume of water produced form this zone. After analyzing this information, it is necessary to propose conformance control measures.

In chapter 4.5 it was suggested conduct a well study according to the "Stop and start (transition mode)" program once a quarter. For the correct conduct of such studies, it is necessary to develop a methodology for the selection and interpretation of samples. Conducting tests in compliance with the developed methodology will minimize errors in studies results.

In chapter 4.4 it was mentioned that lifecycle of tracer systems minimum 1 year for water indicators and 5 years for oil indicators. The objective is to consider the possibility of increasing the lifecycle of tracer systems due to the high cost of well equipment tripping in case of tracer system replacement necessity.

REFERENCES

[1]. Verkhovtsev P.N., Elesin M.V. & Islamgaliev R.F. Experience of multistage hydraulic fracturing in horizontal wells of RN-Nyaganneftegaz // Scientific and technical bulletin of NK Rosneft. 2014.No 2.P. 19-22.2.

[2]. Oil and gas production technology. Gazprom Neft. URL: https://www.gazprom-neft.ru/technologies/production/

[3]. Dobrokhleb, P.. , Kozyrev, A.. , Mishin, A.. , Voitenko, D.. , Kireev, V.. , & D.. Krepostnov. "New Technologies for Effective Recycling of Oil Based Mud. Experience of Prirazlomnoye Field." Paper presented at the SPE Russian Petroleum Technology Conference, Moscow, Russia, October 2017. doi: https://doi.org/10.2118/187696-MS

[4]. Morozov O.N., Andriyanov M.A. & Koloda A.V. & Mukhametshin I.R., Nukhaev MT, Prusakov AV. Experience in the introduction of flow indicators at the Prirazlomnoye field for the study of horizontal production wells // Exposition Oil Gas. 2017.No. 7 (60). S. 24-29.5.

[5]. Chernokozhev D.A. Improvement Of Indicator Technology Research For Evaluating Filtration Heterogeneity Of The Interway Space Oil Formations. Dubna, Russia, 2008.

[6]. Konev D.A., Research of oil reservoirs using the indicator method // Modern high technologies. 2014.No 7.P. 23-26. URL: http://top-technologies.ru/ru/article/view?id=34283 (date accessed: 01/05/2020).

[7]. Basova E.M., Ivanov V.M. & Apendeeva O.K. Possibilities of the spectrofluorimeter "Fluorat-02-Panorama" in the analysis of a mixture of fluorescent dyes // Bulletin of Moscow University. Series 2: Chemistry. 2014.Vol. 55.No. 5.P. 281-295.

[8]. Morozov, O. N., Andriyanov, M. A. & Koloda, A. V. & Shpakov, A. A. & Simakov, A. E. & Mukhametshin, I. R. & Nukhaev, M. T. & A. V. Prusakov. Well

Performance Wireless Monitoring with Stationary Intelligent Tracer Systems on the Prirazlomnoye Oilfield. Paper presented at the SPE Russian Petroleum Technology Conference, Moscow, Russia, October 2017. doi: 10.2118/187767-MS

[9]. Raghavan R., Chen C. Fractional Diffusion in Rocks Produced by Horizontal Wells with Multiple, Transverse Hydraulic Fractures of Finite Conductivity // Journal of Petroleum Science and Engineering. 2013. Vol. 109. P. 133-143.

[10]. Clarkson C.R., Qanbari F. & Williams-Kovacs J.D. Semi-Analytical Model for Matching Flowback and Early-Time Production of Multi-Fractured Horizontal Tight Oil Wells // Journal of Unconventional Oil and Gas Resources. 2016. Vol. 15. P. 134-145. DOI: 10.1016/j.juogr.2016.07.002.

[11]. Barkhatov E.A. & Yarkeeva N.R. The effectiveness of using multi-zone hydraulic fracturing in horizontal wells // Bulletin of the Tomsk Polytechnic University. Engineering of georesources. 2017.Vol. 328.No. 10.S. 50-58.

[12]. Kuznetsov M.I. & Chernokozhev D.A. Quantitative assessment of the conductivity of fractures in oil reservoirs based on the results of indicator studies // Karotazhnik. 2014.No 12 (246). S. 36-42.

[13]. Chen Z., Liao X. & Zhao X. & Zhu L. & Liu H. Performance of Multiple Fractured Horizontal Wells with Consideration of Pressure Drop within Wellbore // Journal of Petroleum Science and Engineering. 2016. Vol. 146. P. 677-693. DOI: 10.1016 / j.petrol.2016.07.009.

[14]. Yarkeeva N.R. & Khaziev A.M. Application of hydraulic fracturing to stimulate oil flow in wells // Oil and Gas Business. 2018.Vol. 16.No 5.P. 30-36. DOI: 10.17122 / ngdelo-2018-5-30-36.4.