THE COMMUNITY OF OIL WORKMEN PRESENTS

AIRVENTO TGT

ECO-FRIENDLY AND HIGHLY EFFECTIVE TECHNOLOGY TO **GATHER SHALE OIL**

WHITE PAPER

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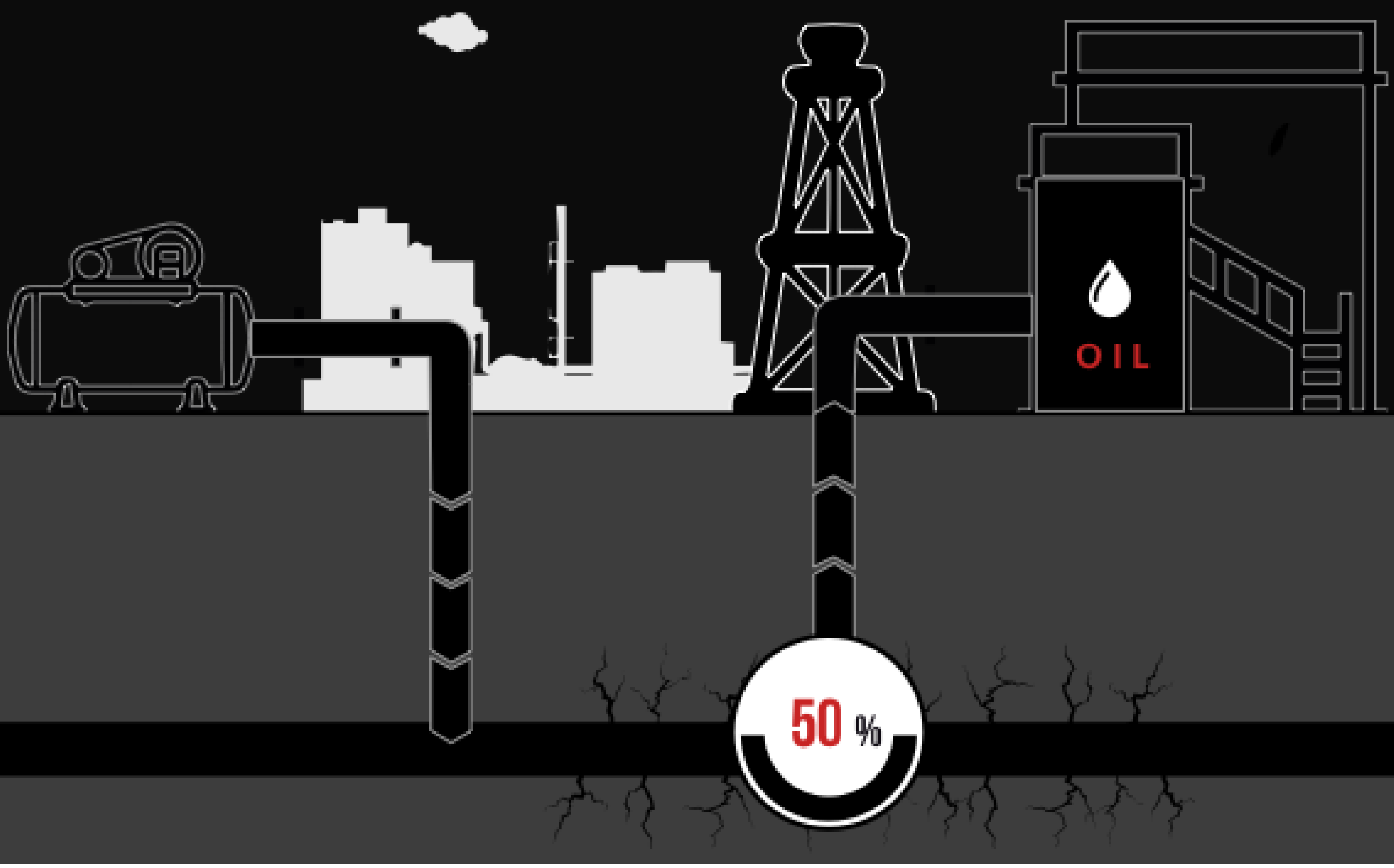

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INTRODUCTION

In the near future, the oil industry will face major changes. Only innovative companies, capable of extracting hard-to-recover hydrocarbons will remain in the market.

The innovative activity of REVOIL Company is based on the application of thermal-gas treatment using oxygen-enriched air. (AirVento TGT technology).

This technology allows enhancing oil yield of low-permeability shale deposits and its analogs, such as the Bazhenov formation reservoirs.

This project seems to be more attractive than many other alternative methods, which are focused on oil production maintenance, such as offshore petroleum production, since well drilling as well as infrastructure development onshore are much cheaper than implementation of the same activities offshore. Moreover, it is much easier to control potential oil spill onshore. In case of emergency offshore, it is most commonly eliminated with huge environmental losses, for example, the accident on Deepwater Horizon platform in the Gulf of Mexico.

Engineered within the project specific monitoring systems and improvement of oil production efficiency, describe this project as “green” one. Recovered on the field oil-associated gas is injected back, in order to reduce the impact on the environment and to enhance oil recovery.

The implementation of AirVento TGT technology will reduce hydrocarbon production costs by means of increasing oil production level. An important component of the financial model is relatively low expenditures on tax dues, since Russia's tax legislation provides preferable terms for tight oil extraction.

According to International Energy Agency, Russia’s shale oil reserves make up about 12 billion tons. AirVento TGT technology will boost oil recovery of these deposits from 5% to 50%, which is proportional to an increase of 5.4 billion tons of oil.

1. OIL PRODUCTION FEATURES

1.1. Oil production process features

Oil production is a technologically complicated manufacturing process, including exploration, drilling and well construction, maintenance, fluid recovery from wells and preparation of produced fluids for further transportation and sales.

Oil on different oil fields can significantly vary in its characteristics: from black no-flow fluid to light low-sulfur hydrocarbon. Moreover, in place there can be solid organic substances, which according to organic theory, in million years can morph into oil under temperature and formation pressure.

Usually, oil is extracted by well drilling, which depth can reach 4-5 km or even more. The majority of the world wells are operated by mechanical means using special oil pumps.

It should be noted, that there are very few non-shale resources, which do not require additional scientific, financial and potential resources for in-situ production.

That is why companies have to use new technologies for oil extraction. After depletion of natural resource for pressure maintenance, when it is not enough for oil lifting, the implementation of secondary oil recovery methods begins. In these reservoirs, external energy is supplied by injected fluid (water), natural or associated gas and other agents.

Conventional oil production scheme is presented in Fig. 1.1.

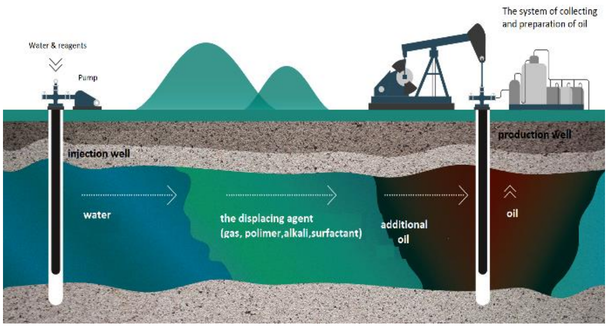


Fig. 1.1 Conventional oil production scheme

1.2. Prospects of shale oil production in the world

The world-known shale oil revolution has changed specialists' view on developing reservoir engineering. A common technology for such kind of deposits is lateral drilling and hydraulic fracturing (frac).

The practice has shown that hydraulic fracturing is inefficient in terms of oil resources usage. The maximum oil recovery rate is only 10%-15%. Moreover, such technology is harmful to the environment, considering that more than 300 tons of chemicals are used for each fracturing operation. Also, in places where hydraulic fracturing is applied, water becomes non potable, air quality deteriorates. In addition, the technology of hydraulic fracturing leads only to a short-term incremental oil production. These facts have played an important role in hydraulic fracturing technology development slowdown.

EIA estimates world shale oil resources from 1.5 to 5.7 trillion barrels.

According to EIA estimates, Russia has more than 75 billion barrels of shale oil, which is about 12 billion tons, USA - 58 billion barrels (~ 8 billion tons) and China 32 billion barrels (~ 4 billion tons). The most successful example of shale oil production is the Bakken formation, located in the state of North Dakota (the USA). In addition, the most promising oil fields are the Eagle Ford in Texas, as well as oil fields in New Mexico and North Dakota.

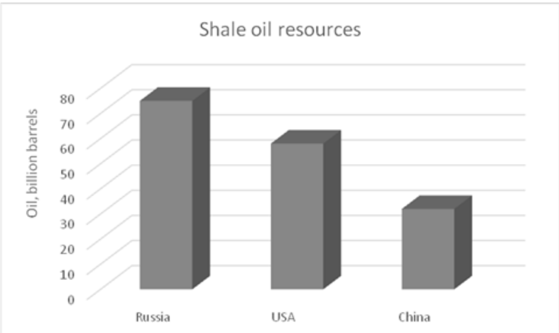


Fig. 1.2 Shale oil reserves in Russia, the USA and China

Russia is the leader in shale oil reserves, thanks largely to the Bazhenov Formation resources potential.

This shale is abundant in the area of more than 1 million sq. km.

Currently, only 5% of the oil reserves is extracted from the Bazhenov Shale deposits, because of lack of technologies for effective development of such deposits. Oil companies develop these deposits using primary recovery method, since traditional methods of maintaining reservoir pressure (for example, flooding) are ineffective, because the layers are hydrophobic.

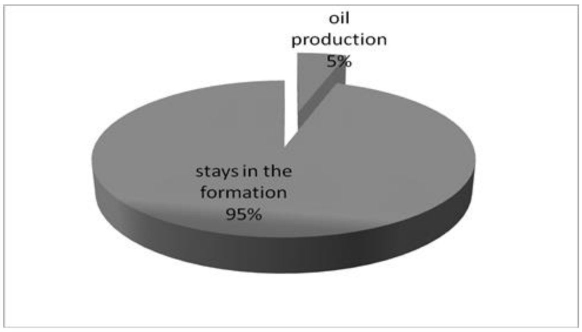


Fig. 1.3 Current oil recovery of the Bazhenov formation

Criterion	value	Bakken	Wolfcamp (Permian)	Eagle Ford	Bazenov formation	Domanik formation
porosity,%	> 3	3–15	~ 7	~ 9	2–17	1–10
the content of organic,%	> 3	3–21	~ 5	2–11	5–12	2–10
reflectance of vitrinite,%	0,6–1,4	~ 0,63	~ 1	~ 1,2	0,7–1,5	0,6–1
The content of siliceous and carbonate difference,%	> 30	> 40	> 60	> 70	> 30	> 30
The thickness of the layer, m	> 15	~ 24	~ 360	~ 90	30-60	50-300
depth,m	900–3000	2700–3200	1650–3000	800–3500	1950–3600	0–4000
Animalne formation pressure		+	+	+	+	+

Fig. 1.4 Comparison of geological characteristics of shale formations in Russia and the USA

Comparing geological and physical characteristics of the Bazhenov formation and similar objects with significant oil influx, their high similarity should be noted.

1.3. Efficiency of the shale formations development technology

Our AirVento TGT technology is based on injection of air, enriched with oxygen, in place via dedicated injection well and its regulation. Airborne oxygen reacts with hydrocarbons in place, reaction products provide efficient oil displacement from the shale, as a result, thermal energy is released and is consumed for warming up the deposit, consequently, additional synthetic crude oil is formed from solid organic substances. Moreover, additional fractures are formed, which are known as fracturing process.

Thus, an important advantage of our technology is not only a short-term increase of oil production, but also a significant increase in oil recovery rate from reservoir, from 3-5% to 40-50%.

1.4. The use of innovative technology for enhanced oil recovery

It is the technologies of enhanced oil recovery that will be given priority in the future, since they effectively use in-situ resources.

According to some estimates, an increase of the oil recovery rate of only 1% will increase technically recoverable oil reserves by 88 billion barrels, which is almost three times as high as current level of annual production.

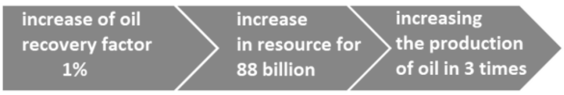


Fig. 1.5 Scheme of efficiency of introduction of recovery rate increase technologies

2. INNOVATIVE TECHNOLOGY OF OIL PRODUCTION AIRVENTO TGT

2.1. The essence of AirVento TGT technology

AirVento TGT technology was developed by REVOIL technical team on the basis of analysis of the best world practices in this sphere. New approaches allow increasing oil recovery of the Bazhenov formation and its analogues many-fold. The technology can be adapted for the development of high-viscosity oil deposits.

The principal technological scheme of its implementation is schematically presented in the figure below. More simply, AirVento TGT is the injection of air, enriched with oxygen and water, into the layer.

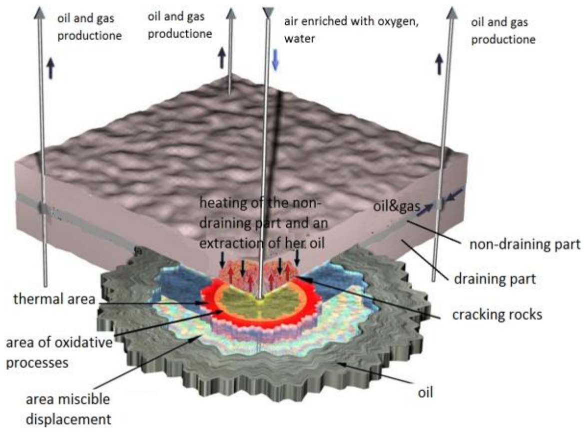


Fig. 2.1 AirVento TGT technology features

Due to the injection of these working agents in the reservoir, a number of processes, that positively influence the oil production, are implemented:

1. During the oxidation processes, **CO_2, CO, NGL are released** in the layer. These gases provide miscible displacement of light oil into production wells.
2. As a result of high thermobaric conditions in the reaction zone, **additional fractures are formed** - new, previously undrained zones are involved in the development.
3. The heating of rocks affects their water affinity. **Rock properties change to hydrophilic.**
4. The increased oxygen content in the injected mixture in comparison with the injection of atmospheric air, **neutralizes the negative effects of nitrogen**, since this gas dissolves poorly in oil and breaks through quickly, restrictiong the hydrocarbon extraction.
5. High temperature and pressure in the reservoir provide the conditions **for the transformation of solid organic matter**, which stands for one quarter of the Bazhenov formation's layers - **into synthetic crude oil.**

Thus, the natural oil formation takes place during kerogen destruction under katagenesis in conditions of moderate temperatures and pressures for hundreds of thousands and million years. It is possible to obtain additional amounts of oil from kerogen by accelerating katagenesis of buried organic matter by means of a higher temperature stimulation on layers. This method is currently the most realistic and promising one.

AirVento TGT technology is an innovative development which implements the following activities:

1. The injection of working agent, enriched with oxygen into the layer (air, enriched with oxygen).
2. Joint injection of oxygen and water in the calculated ratio.
3. Regulation of the rates of working agents injection on the basis of a geological-hydrodynamic model.
4. Monitoring of the technology based on the control of the operation parameters of metering units with a block of gas analysis equipment, which constantly calculate oil and gas flow rate, temperature of fluids, the content of gas blend composition online.
5. Drilling of special injection wells, capable of carrying high loads during the implementation of AirVento TGT.
6. Collecting associated petroleum gas and injecting it back into the reservoir in order to reduce the impact on the environment and improve oil recovery.

The implementation of such measures at particular area in order to confirm calculations of high value of oil recovery up to 40-50% makes this project unique.

2.2. The mechanism of in-situ processes during the implementation of technology

As the oxidation front moves, several distinct zones are formed in the layer. The highest temperature is reached in the oxidation processes zone, with the figures of about 250-350 ° C.

Heat transfer to the area before the zone of intense oxidation processes is carried out by energy convection, and by means of heat conduction. Convective heat exchange is carried out, basically, by a flow of nitrogen, carbon dioxide and evaporated fractions of oil and water. As a result, a zone forming a rim of hot water and light hydrocarbons is formed in front of the intense oxidation processes zone. In the absence of oxygen, chemical reactions come to a halt. Further, ahead of the zone of hot water and light hydrocarbons, the temperature in the reservoir is characterized by its initial level.

At the displacement front, conditions for the realization of the miscible displacement, which leads to more complete recovery of oil from the layer, are created. Practically all positive effects of the mechanisms of various modifications of gas and thermal methods for increasing oil recovery are implemented.

In addition, **for the first time in the world** an important feature of the Bazhenov formation deposits, which are characterized not only by high reservoir pressure, but also by high reservoir temperatures (above 60 ° C), is used.

These reservoir conditions provide full oxygen consumption during the injection of the working agent, as well as generation of a high-efficient displacing gas agent **ensuring a critical oil recovery increase**:

- Due to the carbon dioxide formation as a result of oxidation reactions;
- By enriching the displacing gas agent with light oil fractions, which are released from the reservoir oil due to the impact of thermal energy, formed during the exothermic oxidation reactions of the injected oxygen of air and hydrocarbons.

It should be noted that for the conditions of the Bazhenov formation, the water injected with the air is converted to steam with the high temperature up to 300-350 ° C. This steam temperature makes it possible to increase significantly the fracturing and drainage zone of light oil from the matrix. In addition, under the given conditions, the matrix part of the deposit, from which oil is subsequently recovered because of the conversion of kerogen, is heated.

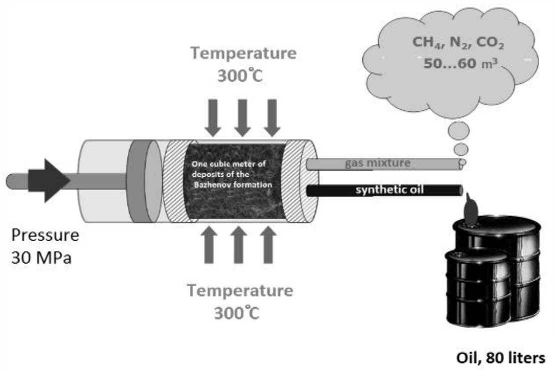


Fig. 2.2 - Scheme of oil production from the rocks of the Bazhenov formation during injection of oxygen enriched air into the layer

According to estimates, it is possible to extract up to 80 liters of additional oil from 1 m^3 of the rock of the Bazhenov formation while heating it.

3. WHY DOES OUR TECHNOLOGY AIRVENTO TGT HAVE THE HIGHEST EFFICIENCY?

Based on the information above, the presented development is aimed to solve a number of large-scale problems related to the development of hard-to-recover reserves. At the same time, AirVento TGT technology can be used in various geological and physical conditions. The results obtained at the area will become the basis for large-scale implementation of innovative development everywhere. Application of the technology makes it possible to arrange cost-effective development of a number of fields, the development of which has been suspended or used to be inefficient, both in technologic and economic terms.

According to calculations, additional investment for unique installation of reservoir stimulation equipment, estimated at 10% of the main project costs, will ensure a multiple increase of oil production. Geological risks will be reduced by attracting the best world specialists in this sphere. In addition, the very reservoir stimulation process with the help of the technology contributes to the improvement of reservoir properties, in particular, to the formation of additional fractures, which greatly reduce the risks of the lack of significant communication of the producing well with the zone of high permeability.

3.1. The technology exploitation leads to improvement of reservoir properties

The new development takes into account positive experience of thermal rims formation in the layer and control over their size during heat transfer air injection into the layer, and therefore provides the injection of not only air enriched with oxygen, but also of air-water mixture, including their alternations. This allows not only increasing the size of the undrained layers heating zone laterally, but also controlling vertical size of the heating area by optimizing the air-water ratio of the injected oxygen-containing mixture and the rate of its injection. There are many other positive consequences of this development. The main consequence is synergistic effect, which is obtained not only from the integration of gas and thermal stimulation of in-situ combustion, but also from hydrodynamic stimulation of injected water.

The injection of water and air, enriched with oxygen, allows accomplishing synergistic effect of thermal and hydrodynamic drags. At the same time, according to the field experience, hydro-stimulation shall provide an advanced improvement of the filtration characteristics of the Bazhenov formation rocks, containing oil and kerogen. Thus, this process will lead to acceleration of thermal effect expansion and increase of its efficiency, resulting in improvement of reservoir properties and, eventually, in increase of oil recovery ratio.

3.2. Oil is displaced from the reservoir by an effective working agent containing CO_2

The high temperature level applied in drained zones (up to 300 ° C and above) along with high reservoir pressure (over 200-250 atm) provide highly efficient oil displacement by water pumped into the reservoir together with air. As a result, the miscible gas agent and steam are expected to provide almost complete displacement of reservoir oil, in the areas that are involved in oil displacement.

3.3. Implementation of the technology allows to get synthetic oil from kerogen

Injection of air-water mixture ensures the creation of a heat rim in the drainable zone, the rate of movement and the temperature level of which must be regulated by the size of air-water ratio and rate of air injection. Thermal energy has a decisive influence on heating of the surrounding undrained zones and the extraction of light oil and hydrocarbon gases from it.

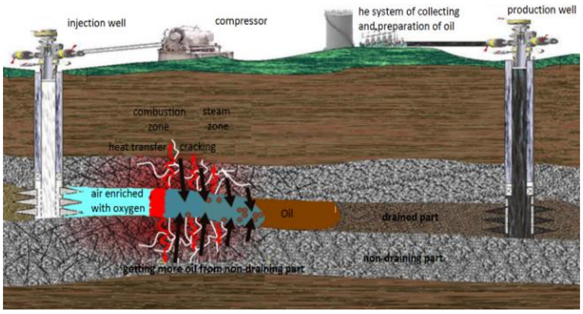
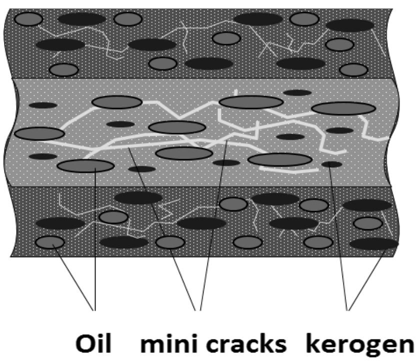


Fig. 3.1 Scheme of in-situ processes while the implementation of AirVento TGT technology

In this regard, it should be reminded that when injecting oxidizing agent only, the heating ahead of the combustion zone is carried out mainly by conductive means. As a consequence, the heating zone remains basically behind the combustion zone. The transition to injection of water-air mixture leads to a substantial increase of convection component of heat transfer, therefore, the heating zone in front of the combustion zone grows. According to studies, optimal parameters of the thermal rim, at which the maximum heating of the matrix is ensured to extract hydrocarbons from it, are established.

Before applying the technology



During implementation of the technology

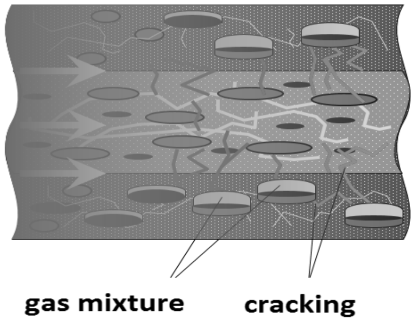


Fig. 3.2 Scheme of technology implementation

Water-air ratio of the working agent pumped into the reservoir according to mathematical studies is about 0.008 m3 / Nm3. So it is necessary to pump very little water in order to regulate in-situ processes.

For the maximum possible utilization of AirVento TGT technology’s high potential, its technical and technological components should primarily contribute to the expansion of the drainage area and thermal stimulation, as well as to ensure, on this basis, the maximum possible oil recovery.

4. COMPETITIVE ADVANTAGES OF AIRVENTO TGT

4.1. Practical experience of shale reservoirs exploitation on the Bazhenov formation

Over the past thirty years, the development of the Bazhenov formation has been carried out only by means of natural drive. Although the areas under development were often characterized by high productiveness, achieved oil recovery rate was estimated at 3-5%. Inefficiency and unpromising use of natural drive of reservoir energy depletion are determined by unusual features of reservoir properties and oil and kerogen content. In particular, the recovery of hydrocarbons in this case takes place practically only from drainage zones, the cavitation volume of which is much lower than of undrained zones. In addition, such method of development does not involve the resources of kerogen-solid organic matter.

4.2. New approach to reservoir development

A fundamentally new approach to the development of the Bazhenov formation and its analogues is operated on the basis of AirVento TGT technology.

AirVento TGT technology provides:

- Significant increase of oil recovery from drainage zones due to in-situ transformation of injected air into the effective miscible displacing agent and its combination with thermal-steam and hydrodynamic drag.
- Introduction into effective development of matrix zones due to thermal action from drainage zones, and its combination with hydrodynamic drag.
- Extraction of additional oil and hydrocarbon gas by pyrolysis and kerogen cracking in drained and undrained areas.

The fundamentals of the new development of AirVento TGT technology are based upon large volume of laboratory studies, the results of which are widely published in the public media, in particular:

- The dependence of the Bazhenov formation rocks reservoir properties on temperature is known. According to these results, well flow rate, cumulative oil production, drainage area strongly depend on reservoir temperature.
- It is known that when the rock is heated over 290 ° C, light oil is extracted from micro-cracked undrained matrix, the value of which is comparable and may even exceed the amount of extracted light oil from macro-fissured rocks (Figure 5.1).

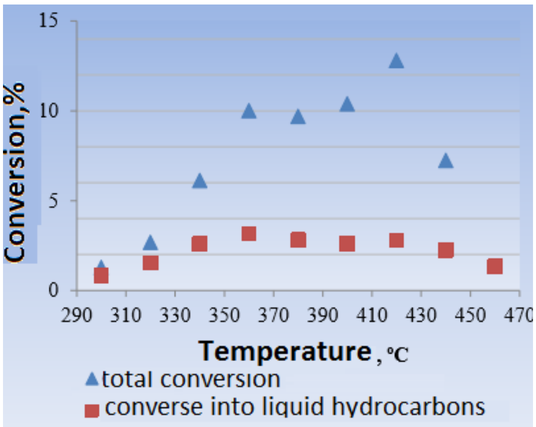


Fig. 4.1 Dependence of oil seepage from the Bazhenov formation rocks on temperature

- Hydro-stimulation leads to additional fracturing.
- All lithotypes of the Bazhenov formation rocks contain kerogen. Volume content of kerogen in lithotypes varies within a wide range starting from 4% in carbonate rocks up to 45% in clay-siliceous-kerogen rocks. Average volume content of kerogen in the Bazhenov formation rocks is 23%.
- Kinetics of kerogen oxidation is higher than of light oil heavy fractions. This fact is important not only for the implementation of active in-situ oxidation processes, but also for ensuring the safety of AirVento TGT technology.

5. TECHNOLOGY EFFICIENCY

Within the framework of this section, the technological efficiency of AirVento TGT technology has been evaluated.

At the first stage of technological efficiency calculation the geological model of the Bazhenov formation layer is reviewed.

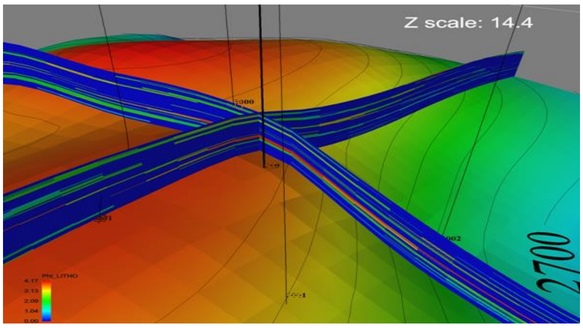


Fig. 5.1 General view of the geological model

Further in the framework of the new technology efficiency estimation, calculation of the development parameters of the test-area, using hydrodynamic modeling (CMG STARS software), was performed.

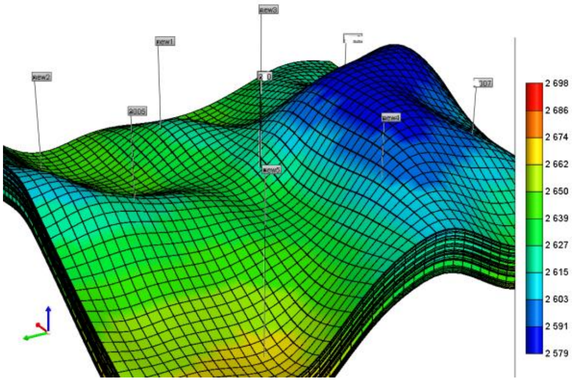


Fig. 5.2 General view of the oil field's area

The calculation method provides for the creation of a test-area at the average field in Western Siberia using the new technology of enhanced oil recovery - AirVento TGT technology.

To adjust the processes occurring inside the Bazhenov formation rocks, when implementing AirVento TGT technology, a thermo-hydrodynamic linear model of the reservoir's section was used. This model allows simulating the mechanism of oil displacement process when introducing AirVento TGT technology.

A distinctive feature of the model is that it has taken into account the following processes that take place when implementing AirVento TGT. Schematically, the main features of the calculated geological-hydrodynamic model are shown in the figure below.

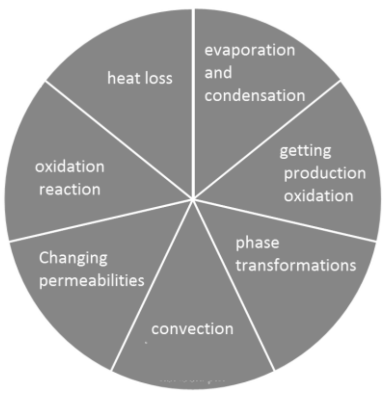


Fig. 5.3 Features of the reservoir model during implementation of the innovative technology

Thus, the geological-hydrodynamic model has the following features:

- Exothermic chemical oxidation reaction of organic matter by aerial oxygen;
- Formation of oxidation products (CO, CO_2, coke);
- Phase transitions due to changes in thermodynamic state of the system;
- Evaporation and condensation of light hydrocarbon fractions;
- Dissolution of light hydrocarbon fractions, CO and CO_2 in oil;
- Change of end points and shape of relative phase permeability curves and capillary pressure of the three-phase system depending on temperature and surface tension;
- Heat transfer due to thermal conductivity and convection;
- Heat losses in upper and lower contacts of zone due to thermal conductivity.

In case of linear filtration model, a hypothetical oil-saturated element of a layer, lying at a depth of 2750-2760.5 meters and having a thickness of 10.5 meters, is considered.

Linear model of reservoir is two-dimensional, block-centered 6-layer, consisting of 900 hydrodynamic grids. The figure below shows its vertical section.

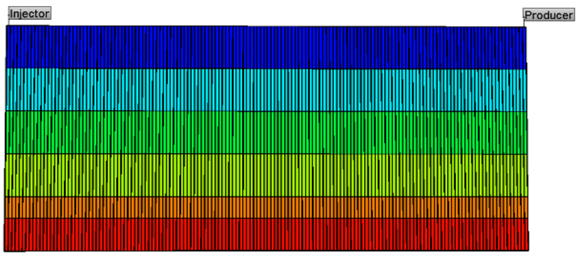


Fig. 5.4 A linear filtration model for studying the basic laws of oil recovery using AirVento TGT technology

In the model, 1,2,3,5 and the 6^{th} layers are impermeable and have matrix properties; the 4^{th} layer is a drainable interlayer with permeability of 10 mD. The matrix, the drained layer and the surrounding rocks are homogenous and isotropic laterally; they have the same and constant initial temperature, but differ in their thermophysical properties.

In Table 5.5. the distribution of the model thicknesses, which were constant in all versions of calculations, is presented. At the same time, geological and physical characteristics indicated in Table 6.2 did not change in the versions of calculations.

Linear filtration model			
Model size, m	Grid size, м.		Model dimension X*Y*Z Number of grids
lx = 750	X	5	150×1×6 900
ly = 1	Y	1	
h =	Z_{1-3}	2	
	Z_4	2	
	Z_5	1	
	Z_6	1,5	
Total layer thickness, m	H	10,5	

Table 5.5 Reservoir model characteristics

Reservoir properties	Unit of measure	Average
Depth of the layer's top	m	2750
Compressibility of a drained interlayer and matrix	kPa^{-1}	$5 \cdot 10^{-7}$
Initial reservoir temperature	ºC	107
Initial reservoir pressure	kPa	33100

Table 5.6 Geological and physical characteristics of the reservoir model

In the linear filtration model, the production and injection wells are located in the last grids of the 4th layer model, as shown in the figure above.

A constant flow rate of the injected agent was set as a boundary condition in the injection well's model. Bottom hole pressure in the injection well depends on the density of the fluid in the wellbore. It grew with an increase of water-air ratio, while wellhead pressure was considered constant - 350 atm.

To create a model of reservoir oil, oil from the Bazhenov formation deposit was taken as a basis.

The composition oil model is represented by two components only:

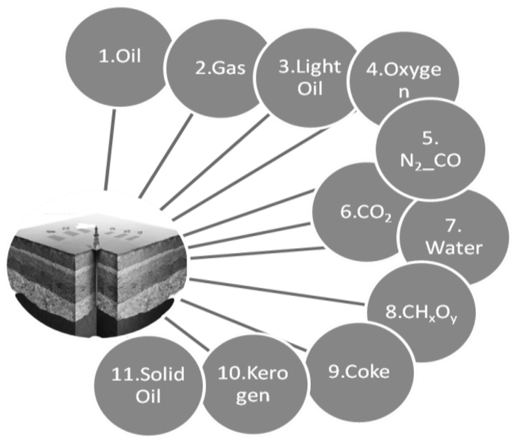
- Oil - wide fraction of medium and heavy hydrocarbons;
- Gas - wide fraction of light hydrocarbons.

The resulting oil components are considered to be basic and characterize the oil, initially presented in the formation

Local water and water, formed as the result of chemical reactions, is represented in the model by the component - *Water*. The injected working agent (*N2_CO* - 50%) and oxygen (*Oxygen* - 50%).

The products of oxidation and degradation reactions are carbon-nitrogen monoxide (*N2_CO*), carbon dioxide (*CO2*), hydroxides (*CHxOy*), medium-hydrocarbon fraction (*LightOil*) and coke (*Coke*). As kerogen, two additional components were created - *Kerogen* and *SolidOil.*

Thus, the layer contains the following components:



Gas, LightOil, CO2, Water and *CHxOy* components are filtered both in liquid and gas phases; filtration of *O2 and N2_CO* components occurs only in gas phase and *Oil* component is filtered only in liquid phase. Filtration of *Coke, Kerogen* and *SolidOil* components does not occur, since they are in the original state of solids.

According to the concepts of chemical processes during the implementation of AirVento TGT, taking into account the capabilities of the thermohydrodynamic simulator, the following chemical reactions were carried out in the research model:

1. Oil + Oxygen ==> CHxOy
2. Gas + Oxygen ==> CHxOy
3. CHxOy + Oxygen ==> Water +CO2 + N2_CO
4. Oil ==> LightOil + Coke
5. Oil + Oxygen ==> Water + CO2 + N2_CO
6. Light Oil + Oxygen ==> Water + CO2 + N2_CO
7. Coke + Oxygen ==> Water + CO2 + N2_CO

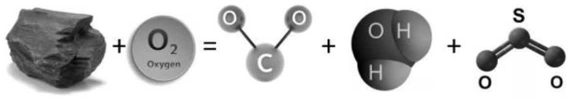
Oil pseudo-component is subjected to two oxidation reactions, one of which results in formation of the finished products such as *Water, CO2* and *N2_CO* components, and the other - in the formation of the intermediate component *CHxOy*. In addition, *Oil* is subjected to decomposition reaction to form *LightOil* pseudo-component and coke (*Coke*).

Gas pseudo-component's molecular weight is less than the molecular weight of pentanes (25 g/mol), there will be practically none of it in the oxidation reaction zone.

CHxOy component, formed as an intermediate product of the oxidation reaction, as well as decomposition of *Oil* pseudo-component reaction product - *LightOil* pseudo-component, participate in the combustion reactions to form final products in the form of *Water, CO2* and *N2_CO* components.

The considered reactions are fundamental for describing the chemical processes that occur during AirVento TGT implementation, but they are not sufficient in the conditions of the Bazhenov formation. The presence of kerogen in the Bazhenov formation and its chemical activity under high temperatures require specification of additional reactions.

To determine the combustion reaction of kerogen in the model, an empirical formula was used, which was obtained from the results of laboratory studies and used to recalculate the heating effect on absorbed oxygen from kerogen combustion:



$C_{25.61}H_{35.61}O_3S_{0.24}+O_2 =CO_2+H_2O+SO_2$

The molecular weight of kerogen is 0.4 kg/mol.

Taking into account hydrocarbons formation from kerogen, two pseudo-components *Kerogen* and *SolidOil* were initially created, which are both in solid state and have identical physical properties. The first one is designed to simulate that part of kerogen which, as a result of thermal degradation, remains in solid residue and forms fuel for combustion reactions. In turn, *SolidOil* simulates that part of kerogen, which corresponds to the formed amount of hydrocarbons. Thus, the model contains the following two reactions, through which the presence of kerogen and its chemical activity are given:

1 *Kerogen* + *Oxygen* ==> *Water* + CO_2

1 *SolidOil* ==> *LightOil*

The initial quantitative content of *Kerogen* and *Solid Oil* pseudo-components in the model is set in such a way that their total volume content per 1 m^3 of the drained layer is 4%, 60% of which refers to the first and the remaining 40% - to the second pseudo-component, respectively. According to laboratory experiments, 4% kerogen content corresponds to its content in carbonate rocks, which are supposed to compose the drained layer in the research model.

The main characteristics of the basic version calculations of the Bazhenov formation development are given in the table below.

Parameters	Values
Recovery mechanism	AirVento TGT
Well spacing, m	750
Bottom hole well pressure, MPa	
- number of production wells (minimum)	12
- number of injection wells (maximum)	45
Well in use, unit fraction	
- production wells	0.9
- injection wells	0.9
Water cut limit during decommissioning of production wells, %	98

Table 5.7 Characteristics of the development calculation case of the Bazhenov formation deposit section

The decommissioning of production wells in the calculations for the implementation of AirVento TGT was carried out when the water cut reached 98%, or when the threshold value of gas factor reached 5000 m^3/m^3. Bottom hole pressures of production wells were limited by saturation pressure. Injection ratio was determined from the condition of maintaining average reservoir pressure of 0.9 - 1.1 from the initial reservoir pressure. The following values are also set in the calculation:

- The minimum bottom hole pressure of production wells is 12 MPa.
- Maximum bottom hole pressure of injection wells is 45 MPa.

In order to regulate displacement front and ensure high coverage of the impact on each production well, gas flow rate was controlled. If the gas flow rate exceeds the value of $q_{gas} = Q_{injection} / N_{wells}$ ($Q_{injection}$ - current air injection rate into the layer, N_{wells} - the number of operating wells at this time), the pressure increases, resulting in redistribution of the filtration flows, the front changes its direction and spreads more evenly.

The maximum injection rate is maintained at the initial stage of the technology implementation, in consequence of decommissioning of production wells, injection rate is reduced.

As a result of geological and hydrodynamic modeling, the following technological parameters are obtained, represented in the graph.

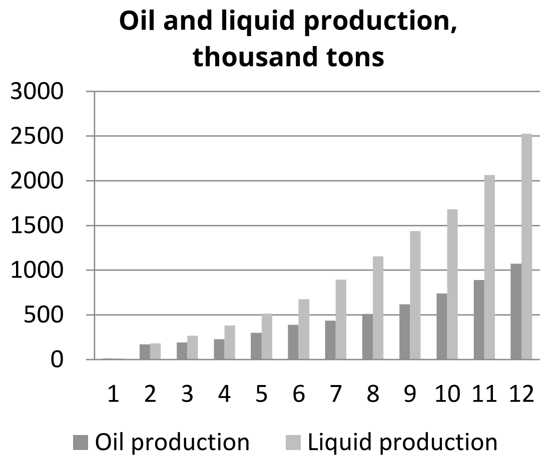


Fig. 5.8 Dynamics of oil and liquid production

The growth of oil production was ensured by commissioning of new wells and the use of AirVento TGT.

6. ECO TECHNOLOGIES AND INTEGRATED USE OF HYDROCARBON RESOURCES

AirVento TGT technology reduces the impact on the environment using associated gas. At the same time, measures that control this technology make it possible to exclude completely the possibility of an emergency during the development of the area. This special system allows controlling composition of the associated gas at any time; if the indicator deviates more than 5%, the monitoring system triggers, while the implementation of the technology will be automatically suspended.

When the technology is implemented, non-isothermal filtration of several components occurs along with exothermic oxidation reactions and associated with them thermodynamic changes of the reservoir fluids' components. Multicomponent mass- and heat transfer, phase state and chemical reactions during the implementation of AirVento technology are presented as interrelated events.

Constant monitoring of changes in the composition of well's fluids is carried out by using online gas analyzer sensors, installed in "Mera-Massomer". "Mera-Massomer" installation with a set of gas analysis equipment provides:

- Input of emergency settings of the measured gas component;
- Transfer of the information on the volume content of o2, co, co2 in associated petroleum gas;
- If o2 content exceeds 1% (volumetric), the electrically-driven gate valve on the production well is automatically closed, the control station of the electric centrifugal pump stops, the light and sound signaling on the operator panel and on the injection well site are triggered.

At the same time, well fluids composition studies are carried out in a chemical analytical laboratory, located at the test site.

7. TECHNOLOGY SECURITY

The project consultants are the authors of numerous patents in the field of developing hard-to-recover hydrocarbon reserves.

At the same time, AirVento TGT technology received a positive feedback from leading oil and gas experts as part of one of the team members' thesis paper evaluation. The comments and recommendations of such experts as (LLC "LUKOIL-Engineering", IGIRGI, OJSC "NK-Rosneft", "TatNIPIneft" R&D Institute, Scientific Research Institute of System Analysis, Moscow A.P. Krylov All-Russian Oil and Gas Scientific Research Institute Joint-Stock Company, Autonomous Non-commercial Organization "Scientific and Technical "ITIN" Association", Moscow Federal State Budgetary Institution "Oil and Gas Research Institute RAS", Federal state-funded educational institution of higher professional education «Samara State University», Samara) are posted publicly on Gubkin Russian State University of Oil and Gas (National Research University) website.

http://www.gubkin.ru/diss2/list.php?COUNCIL_ID=36231.

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