Application of Horizontal - Branched Wells in Complicated Geological Conditions

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ABSTRACT

The carnet level of novel technologies for oil fields development is sufficiently high. The common world practice includes oil reservoir water flooding, chemical and thermal EOR, miscible/immisible oil displacement - injection of hydrocarbon gases, carbon dioxide etc. In the practical development of heavy oil fields, thermal drive plays an especial role.
However, this is a common knowledge, that even the application of high efficient EOR/IOR technologies for oil fields development using vertical wells does not enable to achieve the final oil recovery for more than 40-50% of the estimated reserves.

The main reason for the above is the lack of possibility to reach the high level of the reservoirs conformance by the producing and injection wells, as well as formation sweep during the application of these technologies

The horizontal (HW) and horizontal-branched well systems (HBWS) are one of the realistic and promising way to solve this problem. Such wells have being applying in growing rate in many countries. At that, the main accent has been made on the technical peculiarities of drilling-in of the targets by means of marked wells without their considering energetic characteristics and projected methods of their drainage.

The success of the efficient oil field development with different geological characteristics by means of HW and HBWS will depend on the simultaneous solution of a broad range of technical, geological and technological problems.

Among them the major problems are:
- detailed study and simulation of the geological peculiarities of the formations being developed, their natural behavior and reservoir fluids properties;
- scientific and laboratory-experimental substantiation for the oil reservoirs displacement agents;
- study of the spacing of vertical, horizontal and branched-horizontal wells, enabling the high efficiency of the pay zone drilling-in, and what is still more important, the rational use of natural and artificial reservoir energy;
- study of technical peculiarities of horizontal and branched-horizontal wells construction applicable to certain geological conditions;
- feasibility analysis of the selected options for the development of oil fields, including the evaluation of the best method of oil production.

The actual solution of the above problems is displayed by the examples of the oil fields development in Udmurtia.

INTRODUCTION

The paper is focused on the describing of the principal ways of difficult-to recover heavy oil reserves development by means of horizontal and branched-horizontal wells systems. Being considered are the complex tasks for detail study of the geological characteristics of the project under development, the choice of efficient treatment for oil reservoirs in combination with their being drilled-in by means of horizontal branched-wells systems.

The criteria of horizontal-branched wells systems in different geological conditions have been formulated.

During the consideration of the technological problems of oil fields development using the HBWS, the major conditions for their high-efficiency development at different stages, are highlighted.

DETAIL STUDY OF THE GEOLOGICAL STRUCTURE OF THE PROJECTS BEING DEVELOPED

The application of complicated wells systems for the development of oil fields requires different from traditional cases approaches to the study of their geological structure.

Based on the geological study of the oil pool at the stage of evaluation of the oil reserves or its pilot development, the following detail investigation of the project is carried out:

- the general geological characteristics, describing the type of oil pool and its saturation with oil, gas and water;
- determination of the objects to be developed and the subsequent of putting them into operation;
- study of lithological and petrophysical and reservoir characteristics of all beds of stratigraphic section, their heterogeneity;
- study of physical and chemical properties of the reservoir fluids and gases. For oils with increased and high viscosity the relationship between reservoir oil viscosity and temperature is determined;
- determination of the geothermal factor of the oil pool area, measurement of pressure and temperature of the formation under development;
- study of the oil and gas reserves with the specification of the stratigraphic section of reservoirs;
- general description of oil and gas bearing beds, situated under the crest of the developed object, for the rational design of horizontal well bores and branched-horizontal wells systems profile.

Based on the detail investigation of the oil pool, we have constructed an estimated geological and physical model, which meets the requirements of the mathematical programs for technological forecasting of the oil pool development indices and oil recovery under the preset schemes of complicated wells systems and oil bed treatment technologies.

GROUNDS FOR THE TECHNOLOGIES OF OIL BED TREATMENT

The choice of oil bed treatment technologies is based on the geological and physical criteria with the application of the combined spacing of vertical, horizontal and branched- horizontal wells systems. At the same time it is necessary to consider one of the major factor: the applicable treatment technologies should enable the realization of the HW and HBSW potential for oil recovery at optimum reservoir pressures , i.e. the rates of restoring the reservoir energy during the used treatment technologies should correspond to the estimated top level of production from complicated wells systems. The top level of production derive from the relationship between the total extension of drilling in of the reservoirs by means of wells systems, reservoir characteristics of the pay beds and optimum reservoir pressures.

Thus, the application of complicated horizontal and branched horizontal wells systems the choice of such bed treatment technologies, which could enable the proportional restoration of the reservoir energy in the course of the project development is necessarily required.

For the high viscous oil pools, the most profitable and technologically efficient recommended methods might be the pulse-dosing heat treatment of bed using the system of special injection wells [1,2] as well as thermocyclic treatment of beds through the system of production wells [3]. The application of the above technologies provides a number of essential industrial benefits: acceleration of the thermal drive process at the available capacity of heat generating facilities, economy of resources needed for the preparation of the heat-transfer agent, increase of the producing wells output and thus, the increase of oil production rate, improvement of the reservoirs conformance conditions by displacement, and the final result is the enhancement of the ultimate oil recovery.

SUBSTANTIATION OF COMPLICATED WELL SYSTEMS SPACING

The complicated wells systems should meet the following main principal requirements for high-efficient oil pool development:
- enable the maximum coverage of pay beds by drilling in;
- capital investments for the construction of wells systems should be back paid profitably;
- while constructing the wells systems and during their operation, the safeguarding of the local natural reserves, not included into the current development program, should be provided;
- the complicated wells systems in combination with the applicable bed treatment technologies should ensure the fulfillment of the three basic principles of high-efficient oil pools development:
1) achieving the projected volume of oil production
2) reaching the high final oil recovery
3) gaining the high economic profitability.

HW and HBWS in the drilling-in of the objects being developed may function both as the producing and injection wells.

When fulfilling the technical program for the construction of complex wells systems, there is a number of principal tasks to be highlighted. The major of them are:
- providing the technical safety of drilling-in of the target reservoir, or of the entire beds system of the project;
- ensuring technically the long-term operation of the complex wells systems;
- the monitoring of the technical conditions and the specifications of draining of the horizontal drilled- out wells systems by means of the log services and hydrodynamics tests;
- and evidently one of the main tasks is ensuring the reserves safety within the area of construction of the complicated wells systems.

THE FUNDAMENTAL CRITERIA OF SELECTING THE OBJECTS FOR THE APPLICATION OF HW AND HBWS

Essentially HW and HBWS can be applied in any geological conditions. However, at the current stage, the main limiting factors are related to the technique and technology of their construction.

The preference can be attributed to the objects with the following geological and physical characteristics:
- depth of deposits - more than 2000 m.;
- oil pools with any type of deposition conditions;
- single - bed pools with the pay section exceeding 5 m.;
- multiple - deposits with a broad range of pay sections and their heterogeneity as to permeability and zone continuity;
- objects with carbonate and terrigeneous, porous and porous - fractured reservoirs;
- objects with mine rocks resistant to spontaneous destruction;
- the level of the reservoirs oil saturation or the density of oil is limited by the economical indices, when the applied systems and the development technologies are profitable.

The complex wells systems in combination with the high efficient treatment technologies are used in such cases, when the field operator is assigned to achieve high oil production rates from the geological complicated formations.
The examples of specific technological design and development of several oil fields in Udmurtian using the complex wells systems are described below.

THE GREMIKHINSKOE OIL FIELD, A4 FORMATION: EXAMPLES OF FIELD APPLICATION OF HW AND HBWS

This is the case, when the oil pool has been completed by means of the system of vertical wells and is being commercially developed.
Structurally, the A4 oil deposit is represented by brakhianticline fold with the small angles of the inclination.
The section displays the interceding of carbonate porous-and-fractured reservoirs and thick low-permeable or impermeable layers.

Totally, the A4 formation consist of up to 17 oil saturated layers with thicknesses varying from 1 to 6m. The dense impermeable carbonate rocks have thicknesses ranging from 1.1 to 3.8 meters. Permeability varies within a broad range from fractions to 2.3 Darcy having average value being around 0.150 Darcy. The average porosity is 0.18. The oil is heavy (0.923 grams per cub.cm.), high-viscous (90-180 MPa.s) with low content of dissolved gas (up to 6.0 cub.m/ton). The oil pool has a wide aquifer on the depth of 1000 m. (OWC). The initial reservoir pressure at the OWC equals to 12.5 mPa and the reservoir temperature is 28°C.

The oil pool was drilled in by the uniform triangle spacing with the distances between the wells to be 173 meters. Inverted 7 - spot elements with heat-transfer agent injection into the central injection wells were formed. Bed A4 has been drilled in by producing and injection wells for the entire oil bearing thickness by means of the selected cumulative perforation. The perforation intervals cover the oil saturated thicknesses from 8.0 to 32 meters.

Producing wells rate varies from 10 to 20 tons of liquid and 3,5 to 7 tons of oil per day at the bottom hole pressure of 5 to 7 MPa and reservoir pressure in drainage areas from 7 to 11 MPa. The injectivity rate amounts to 160 tons per day. The injected into the bed heat transfer agent parameters are: injection well head temperature - 260°C, injection pressure - 4.5 to 6.0 MPa.

The total amount of oil produced during the oil pool development period (since 1981) is about 10.0 million tons (approximately 15% of the initially evaluated oil in place). The forecasting for the oil pool development indices, when using the applicable reservoir drilling-in method and the injection of heat-transfer agents show the final oil recovery factor of no more than 35%.

When generalizing the major geological and physical characteristics of the A4 oil pool , it can be noted that the above object is favorable for high-efficient application of the horizontal branched-wells systems in connection with thermal drive methods. The most favorable above factors for this pool may be:
- the convenient deposition depth for the provision and construction of wells having any profile;
- availability of the multizone system with a broad range of the permeability heterogeneity;
- lithological pinching out of certain pay and dense layers;
- availability of the preliminary study of the vertical fracturing of the A4 formation determining the hydrodynamical communication of the deposit;
- the massive oil deposits with the aquifer;
- gross productive formation thickness reaches 85,0 meters;
- the presence of the carbonate reservoirs with double porous and fractured characteristics. The reservoir is resistant to the mechanical destruction;
- high-viscous oils the filtration of which to the short perforated interval is limited.

The construction of horizontal wells with one bore under the above conditions may turn out to be of little efficient or even unprofitable. The branched-horizontal wells systems can ensure the high technological and economical effect.

The main principles of drilling in and development of the A-4 oil pool by horizontal-branched wells

Three options to use the horizontal-branched wells as the means of oil production have to be investigated.

OPTION 1. Drilling in of the complete oil saturated target by horizontal-branched wells system with the formation of the hexagon thermal drive elements using the central vertical injection well (VIW) [Fig.1].
This option includes the formation of elements by three horizontal-branched wells and one central vertical injection well.
Each horizontal-branched well consists of three basic horizontal branches with deviation between them being 120 degrees, located near the top of the target reservoir. Each basic branch contains vertical hole (from 3 and more depending on the length of the basic branch and oil-saturated conformity), ensuring the penetration of the entire gross thickness.
OPTIONS 2. Differs from option 1 by the basic branches being not near the top of the producing reservoir, but within the preset section of the reservoir subdividing it into two independent objects. [Fig.2]
OPTIONS 3. The formation of the upscale thermal drive element, wish has vertical injection well at the triangle vertices, and one horizontal well with three branches (in 120 degrees each) in the triangle center, instead of the 7 spot vertical wells system. Each basic branch also includes the vertically-configurated bores, covering the entire oil-saturated thickness of the target.[Fig.3]
When we compare the characteristics of the above options of the horizontal-branched wells with their analogies vertical wells system, we can figure out the following main advantages of the HBWC:
- reduction of the required number of producing wells (in options 1 and 2 - twice, in option 3-by 6 times);
- significant (5 times and more) increase of the oil withdrawal rate;
- reduction of the total period of the development;
- essential reduction of capital and current costs for drilling in and operation of wells;
- increasing the efficiency of thermal drive process by means of improving the thermal-mass exchange in heterogeneous multizone media and, thus, the increase of the final recovery.

Estimation of oil production using heat-transfer agent in the horizontal-branched wells systems shows the essential increase of the oil production rate, amounting to 10.4-12.7 thousand tons per one element, under the application of the proposed options, and the increase of final oil recovery (up to 0.4) at relatively favorable indices of the heat-transfer agent specific consumption (1.2-3.2 tons per one ton of oil produced due to the process). The maximum effect has been achieved with the systems of consecutive upwards oil withdrawal.

SHARKASK OIL FIELD, A4 FORMATION: APPLICATION OF HBWS

This example pertains to the case, when the oil field had not been drilled in and commercially developed. The production formation of the Sharkansk oil field is A4 reservoir of the Vends stage of the upper Proterozoic. The reservoir is represented by fine grained sandstone and argillites. This is a crest - type oil pool, with aquifer with the absolute OWC level at 2147 meters. The pool dimensions are 5.0 x 4.0 km. The gross reservoir thicknesses 15.7 m. while the average net one is 3.7 m. within the isophach limits - 4 meters, and where the wells are going to be spaced - 8.6 m. Porosity equals to 0.17, avg. permeability - 0.392Darcy, and initial oil saturation - 0.82.

The oil is heavy (0.953 g/cm3), with high viscosity (972.9 MPa·s), with low gas content (3.40 m3/ton). The reserves of the main part of the oil pool make up 5850 thousand tons.

The oil pool drive is natural elastic, the initial reservoir pressure being 16.0 MPa and the temperature 35.5 ^{o}C.

Taking into consideration the geological structure and the reservoir oil characteristics, formation drilling-in option by means of the combined system of vertical and horizontal-branched wells has been projected [Fig.4]. The combination of vertical and horizontal-branched wells systems represents the great practical and scientific interest due to the promising prospects of using the branched horizontal wells for development of hard-to-recover viscous oils reserves.

The length of the net pay penetration by vertical wells is determined as the amount of the net oil-saturated thicknesses, corresponding to the spacing (drilling in) of all the projected and exploration wells, included into the well pattern.

The values of thickness are measured using the maps of the oil-saturated thicknesses of the maps object. This parameter is especially important for horizontal-branched well systems, since the well production characterizes depend on its values. In the proposed option, the horizontal extension of well bores from the vertical is assumed to be from 300 to 500 m. Such bores extention meets the contemporary conditions of the technical readiness of the drilling organization and of the existing construction technologies for the horizontal-branched wells. However, the actual extension of the formation drilling in by the HBWS will be much less than the lengths of the horizontal part. Under the actual conditions, the length of the reservoir drilling-in by the horizontal-branched wells will depend on the number of technical and technological factors applicable for the construction of HBWS. Attributed to the above may be the following factors: profile of increasing curve of the bed entry, profile and design of the HBWS bores within the pay zone, the geological-and-physical characteristics of the pay (thickness, lithological and tectonic interrupt of extension, heterogeneity etc.)

In order to estimate the actual bed drilling-in length by HBWS and with regard to the above factors so-called reservoir drilling-in factor (L r.d.) is introduced.

Then, the length of the reservoir drilling-in will be determined as the following:

$$L_{r.d.} = L_{h.p.} \cdot C_{r.d.}$$

where the L h.p. is the length of the horizontal part of the H B W S.

The C r.d. (reservoir drilling-in factor) is determined depending on the value of the drilled-in oil-saturated thickness of the object being developed. In our case the total drilling-in length of the pay beds with six horizontal-branched wells amounts to 1720 m., which exceeds the length of the bed drilling-in by the system of 16 th vertical wells by more than 20 times. This index is already a convincing prove of higher pay zone drilling-in efficiency and its operation by the HWBS as compared to the vertical wells under the other equal conditions.

During the analysis of such a parameter as the "wells drilling density", it loses its sense for HBWS, if to proceed just from the quantity of wells. In this case, it is rather significant to determine this parameter in conformance with the lengths of pay drilling in by wells. At that it should be based on the drilling-in object conditions by vertical wells. The equation for determination of the drilling-in density by means of using the horizontal-branched wells will be as follows:

$$D_{HBWS} = Pa / Nv \cdot Lc / L_{HBWS},$$

where:

D_{HBWS} - is the horizontal-branched wells system drilling density, with reduction to vertical wells, in hectares per well
Pa - is the oil bearing area covered by HBWS.
Nv - is the number of vertical wells drilled-in at this pattern-the base of comparison.
Lc - is the bed drilling in length by the comparison base wells.
L_{HBWS} - is the length of drilling in by horizontal-branched wells.

The received drilling density value of 0.8 hectare per well shows that the HBWS ensures a very high drilling density and, thus, a significant reducing of the oil filtration length in porous medium having high flow resistance's, i.e. significantly increasing the efficiency of application of natural and artificially created (by injection of agent into the bed) reservoir energy. There is no doubt that such factor will ensure the enhancement of oil production and the increase of the final oil recovery, at the same time reducing the required economic expenses for the oil-pool development processes.
Another specific parameter to be determined is the oil in place per 1 running meter of the drilled in pay thickness. Its comparatively low value for HBWS (1.9 thousand tons per meter) justifies to favorable (not stressed) conditions of oil influx to the HBWS bores, and to the potential feasibly to essentially reduce the duration of oil - pool development and achieve better oil recovery indices.
Proceeding from the specific GEOLOGICAL characteristics of the Vends stage (high viscosity of oil, low net pay sections, relatively small oil reserves etc.), the most efficient, economically feasible and rational may be the cyclic bed heat treatment technology (CBHT). The oil-pool being considered does not contradict to the main criteria of application of CBHT.
Moreover, according to the results of the brief analysis, the CBHT process is one of the most efficient thermal methods in the existing geological conditions. The CBHT process is provided for the entire system of vertical producing wells, and the system of horizontal-branched wells is operated without the stimulation - only in the withdrawal mode. After efficient realization of the CBHT process, the systems of oil displacement by water with the temperatures, not lower than the current reservoir average temperature, are formed.
The calculations show that the development of such oil-pools under the natural reservoir conditions is absolutely impossible due to the lack of sufficient energy provision for the HBWS and a rather low final oil recovery factor. From the range of existing EOR methods, the only applicable for such type of oil-pools are the thermal EOR methods. However even in this case, if the pay is deposited at big depths and if its oil-saturated thickness is not efficient enough, then the choice of thermal drive methods is rather limited. In our opinion, the most rational of them is the CBHT technology.
The application of horizontal-branched wells systems essentially increases the rate of oil recovery (the annual withdrawal rate being 65.8 thousand tons, or 11% of the recoverable oil reserves), and thus increases the final oil recovery by more than 2,5 times compared to the use of vertical wells system. Such results will be necessarily achieved, provided the flow characteristics improvement due to the decrease of reservoir oil viscosity and the maintenance of reservoir pressure.

CONCLUSION

The high-efficient application of complex wells systems for the development of oil fields requires a necessary simultaneous solution of four major problems:
- detail study of geological and physical characteristics of the object to be developed;
- technical peculiarities of running and construction of horizontal and branched-horizontal wells systems;
- substantiation of drainage and oil bed treatment technologies with regeneration of the reservoir energy sufficient for the realization of potential possibilities of horizontal-branched wells systems in certain geological conditions;
- the whole complex of the HBWS construction and operation works shall ensure the protection of reserves.

It goes without saying that the use of complex wells systems is a very promising direction of oil fields development, which is especially true for the hard-to-recover oil reserves.

Table 1

RECOMMENDED PARAMETERS OF WELLS SPACING FOR THE VENDS STAGE

PARAMETERS	Vertical wells	Horizontal- branched wells	Total
Oil bearing area covered by the well pattern, thousand sq. meters	3533	2275	5808
Initial oil reserves covered by the well pattern, thousands tons	1997.0	2950.3	4947.3
The number of wells (well heads)	16	6	22
Length of horizontal part of the HBWS, m	-	300-500	300-500
Net pay penetration, m	78	1720	1798
The well spacing (recalculated for vertical wells), has/well	22.1	0.74	13.7
OOIP per 1 well, thousands tons per well	124.8	491.7	235.6
OOIP per 1 meter of penetrated thickness, thousands tons/m	25.6	1.7	2.75

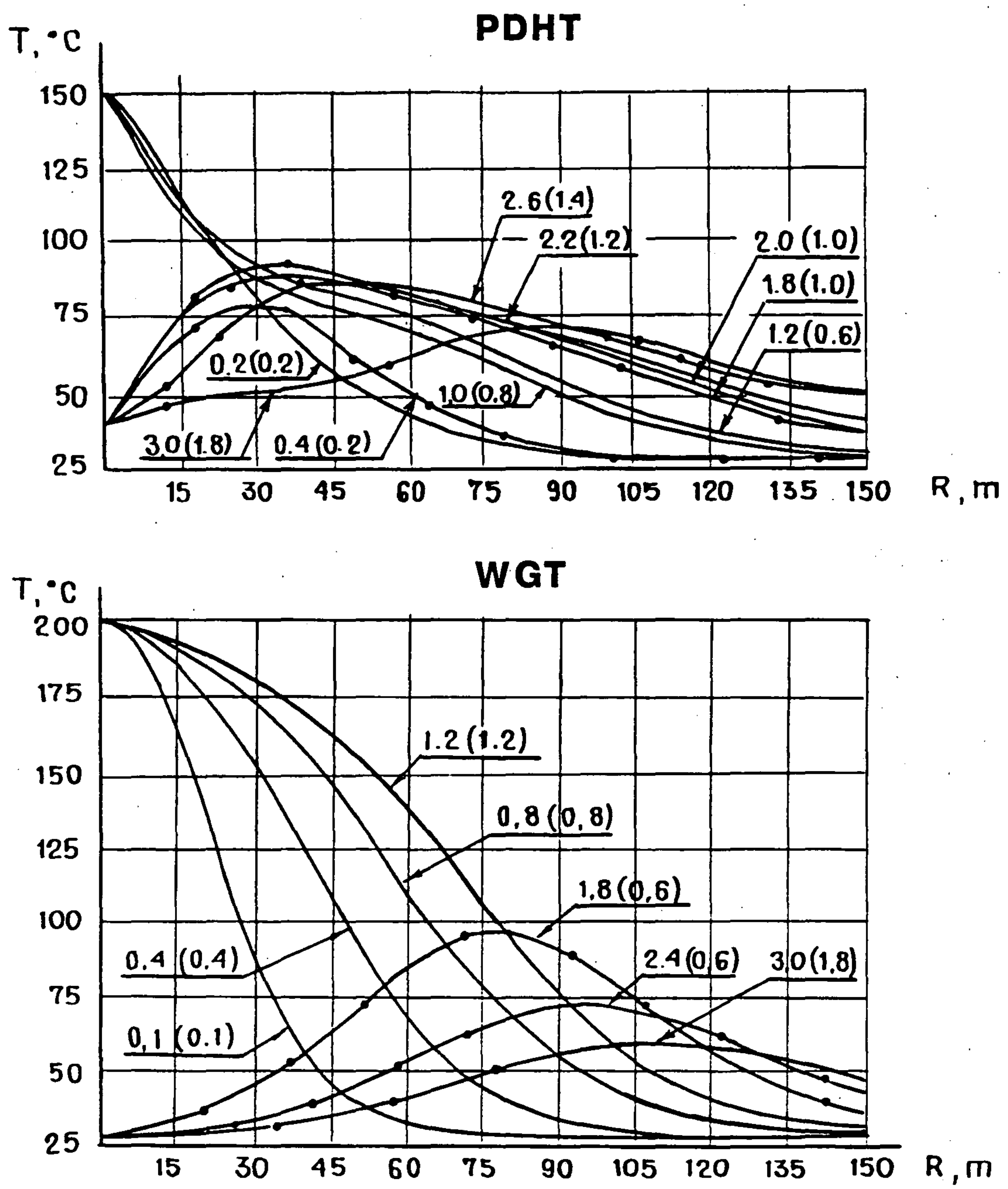

Fig.1 Gremikhinskoye oil field, A4: Temperature profiles

——— temperature profile after heat carrier injections

—•— temperature profile after cold water injections

1,8(0,6) amount of heat carrier and cold water injected in fractions of pattern

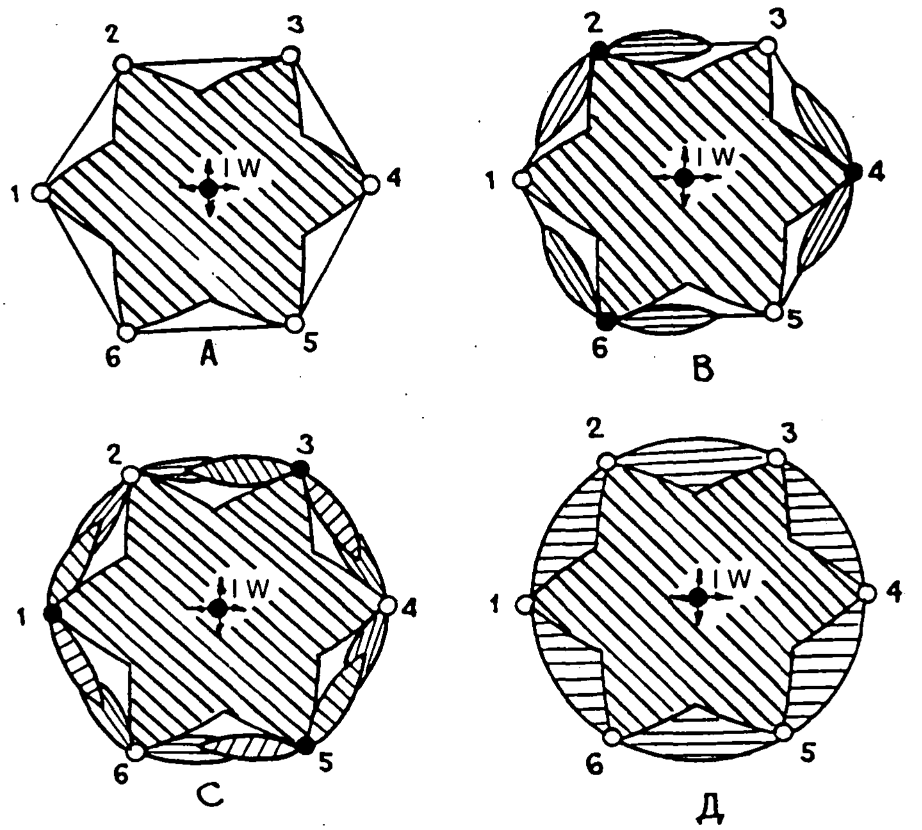

Fig. 2 Thermal cyclic treatment of formation

o - producing well
● - producing well, heat carrier injection
injection well

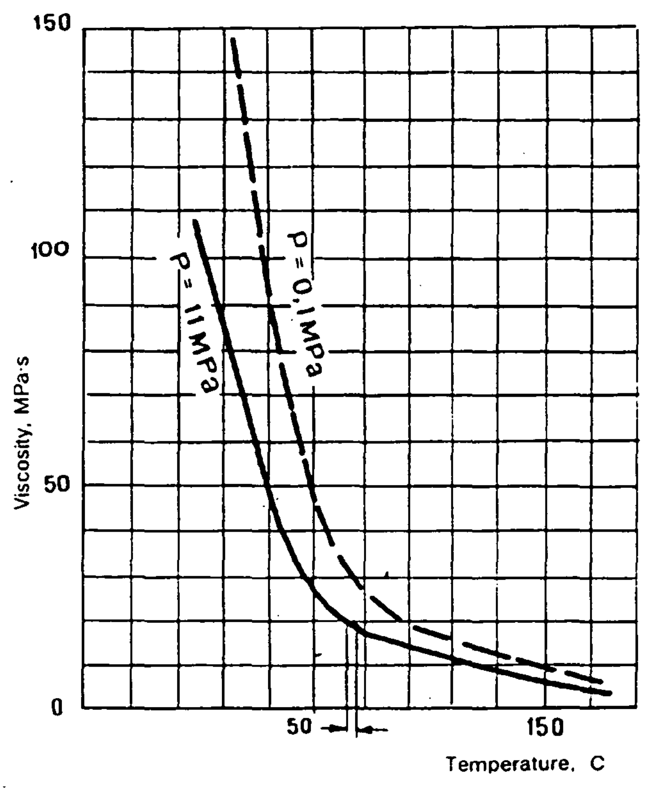

Fig.3 Gremikhinskoye oil field, A4: Oil viscosity versus temperature

-- -- crude oil
—— degassed oil

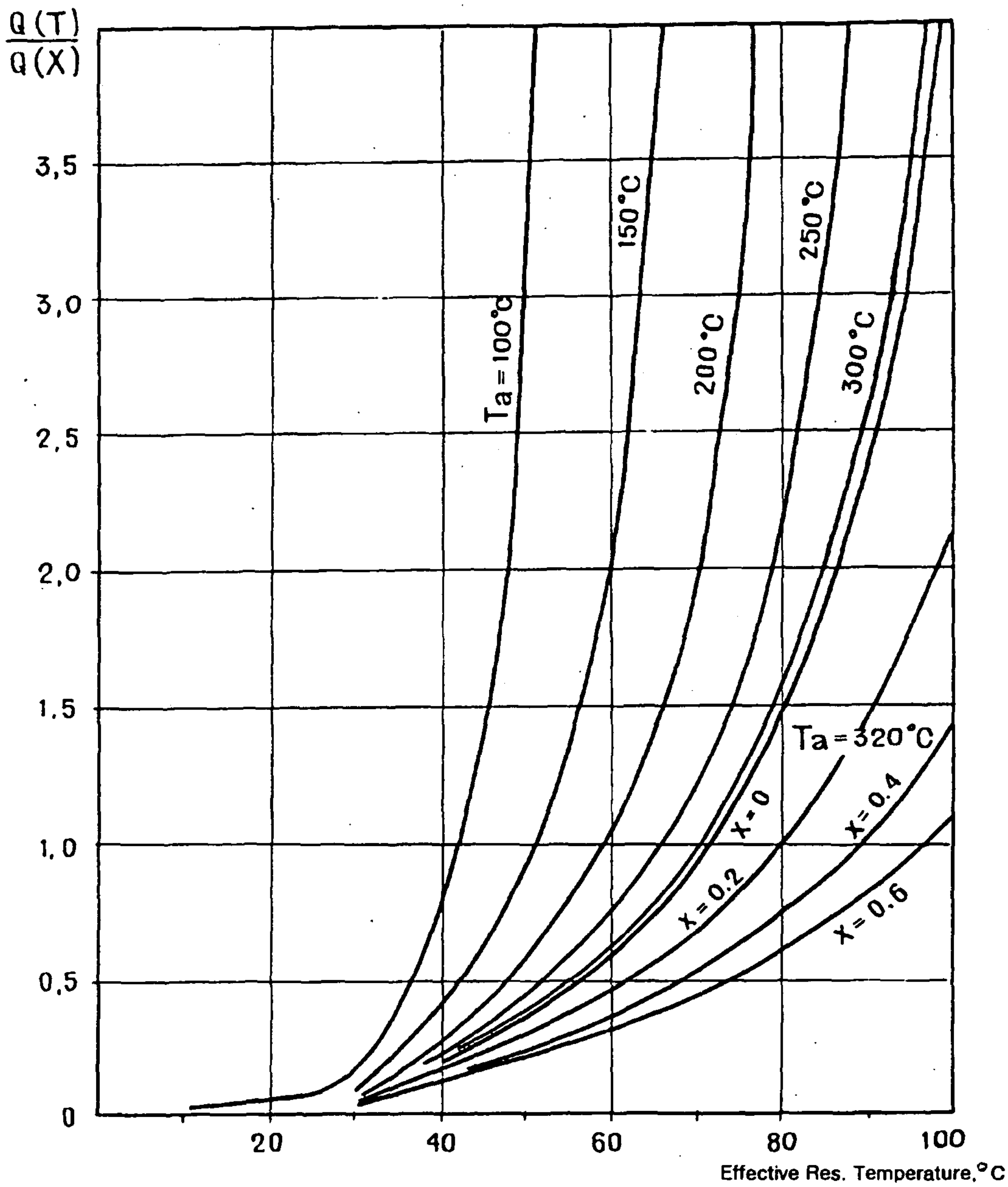

Fig.4 Nomogram
Q(T) - total ammount of required heat carrier
Q(X) - total ammount of required cold water