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THE INFLUENCE OF THE CONTENT OF CLAY MINERALS ON THE EFFICIENCY OF STEAM TREATMENT INJECTION FOR THE BITUMEN OILS RECOVERY

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Abstract

Globally, for the development of bitumen oils thermal steam treatment is considered, since this technology is considered the most effective, but it has a number of problems with the presence of clay minerals in the rock. When clay minerals come into contact with steam they swell, leading to a decrease in the permeability of the reservoir, and therefore a decrease in the final oil recovery. This work assesses the influence of clay mineralization content on the degree of oil displacement under thermal steam treatment by conducting filtration experiments. Steam injection experiments containing low oil saturations of less than 2% resulted in no oil displacement. A solvent based on aliphatic and polar fragments was tested to extract oil in such low-oil saturated systems.

Keywords:

Steam injection;
Bitumen oil;
Clay minerals;
Solvent;
Oil displacement.

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Introduction

The high clay content of the reservoir (clay content - more 10%) reduces the effectiveness of the use of thermal methods leads to swelling of clays and a decrease in reservoir permeability and physicochemical methods due to the high adsorption of chemical products and the depletion of the injected chemical solutions [1,2].

Scientists from the University of Texas [3] investigated problems associated to clay swelling and mineral alteration associated with the thermal effect of steam on the formation. In their study, 12 different specimen of quartz, calcite, dolomite, kaolinite and montmorillonite were exposed to steam (200 °C, 5.5 MPa) in a filtration unit. Quartz and calcite specimens were found to be prone to change with steam injection. Specimen of quartz, kaolinite and carbonate minerals (calcite or dolomite) after exposure to steam showed a decrease in permeability relative to its initial value by 11-22% and a decrease in open porosity by 2-7%. Steam injection in enrichment montmorillonite sandstone led to a decrease in absolute permeability by 84% and to a decrease in open porosity by 8%. The authors of the work identified clay swelling as the fundamental negative influence on the formation, which led to clogging of the pores. This ultimately complicates the applicability of the steam treatment in clay-bearing reservoirs.

In a different study [4], the effect of steam and hot water injection on absolute permeability, relative permeability, wettability, residual oil saturation, and structure of clay-bearing rock is considered in the example of a heavy oil field in Southern Alberta, Canada. Steam was injected at reservoir conditions (32-265 °C, 3.3-7.5 MPa). According to the authors, there are three main reasons for the decrease in the filtration properties of the reservoir:

- 1) Transformation of kaolinite clay into swellable smectite clay
- 2) The process of dissolution and redeposition of salts
- 3) Change in the type of rock wettability (from hydrophilic to hydrophobic)

Research Bennion, D. B., Thomas, F. B., & Sheppard, D. A [4] had a decrease in absolute permeability by up to 90% due to changes in these three factors.

In this study also, a dependence was revealed in the form of a decrease in residual oil saturation with an increase in temperature. The results of experiments on exposure to steam at a temperature of 265 °C showed a decrease in residual oil saturation up to 8%.

The change in wettability (to hydrophobic) was obtained during steam injection. This means that a balance must be found between lowering the Mobility ratio and extracting residual oil from the pores using steam.

In the work [5], the authors consider the modeling of reservoir properties caused by the

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increased content of kaolinite at temperatures from 25 to 300 °C in the oil-bearing sandstones of Alberta. The Alberta sandstones contain vast amounts of ultra-high-viscosity oils, but in most cases these sandstones also contain kaolinite. Kaolinite has two main types of negative effects on the formation when exposed to steam, both of which lead to a change in permeability. At low temperatures, kaolinite affects the transport of particles, at high temperatures (exposure to steam), kaolinite reacts with other minerals and is altered to form smectite and analcime.

The transport of particles at low temperatures depends on hydrodynamic and colloidal forces, and is the main reason for the decrease in permeability. Particle transport is dependent on water chemistry and pH (the higher the pH, then higher the transfer of particles), as well as from the salinity of the water (the lower the salinity, the higher the transfer of particles).

Based on the results of numerical simulations [5], it was found that during steam treatment, the formation reactions of analcime and smectite can be controlled by changing the chemical composition of the injected fluid (steam). However, this can be dealt with by adding Ca^{2+} ions, which significantly reduce the redeposition of kaolinite particles. Therefore, if there is a choice of what to pump, then you need to choose more acidic solutions with a low calcium content.

At high temperatures (with steam injection) and at neutral or alkaline pH, kaolinite can break down and decompose into smectite and / or analcime. Due to its swelling properties it is an undesirable product, leading to a decrease in permeability.

In the work [6], investigation of the effect of steam (150 °C, 6 MPa) on changes in clay mineralogy under a microscope (scanning electron microscopy (Quanta 450)) was carried out. The swelling, transformation and dissolution of clay minerals after exposure to steam in unconsolidated sandstones with heavy oils were considered. Results showed that the swelling of clays increases with increasing pH of the injected solution and decreases with increasing salinity of the injected solution. High temperature and high pH can cause the transformation of clay minerals. Montmorillonite can be transformed into illite or analcime, and kaolinite can be transformed into montmorillonite and analcime. However, analcime is relatively stable so does not pose a great danger to the properties of the formation.

Day, J.J. and Huitt, J.L. [7] investigated the effect of steam and hot water on the properties of the rock. The term «rock softening» is used, which, in fact, means a decrease in the reservoir properties of the rock. This softening of the rock is associated with the partial destruction of dolomite and kaolinite and the formation of montmorillonite in the presence of an excess of silica.

Research has also found that adding even small amounts of ammonia to the injected fluid can help avoid rock softening.

X-ray diffraction analysis of rock samples showed that when ammonia was added to the injected fluid, mica and analcime were formed instead of montmorillonite.

Permeability of sandstone does not change significantly when the agent is injected with the addition of ammonia.

The work [8] considers the change in permeabilities in clay-bearing rocks of Northern Kuwait after exposure to steam. These rocks contain clay content of approximately 9% (mainly smectite and illite). Experiments were carried out on these rocks injecting fluid with different salt concentrations, different pH and different clay stabilizers. When such fluids come into contact with steam, the permeability is significantly reduced. According to the authors, changing the pH or salinity of the water is not suitable for controlling the change in permeability. However, it has been found that clay stabilizers can help deal with this problem (the authors do not disclose the composition of the stabilizers).

In this work physical 1-D modeling of thermal EOR was carried out. Core samples were taken from test drilling well of clay reservoirs to assess the effect of clay content on the feasibility of thermal steam injection and selection of an effective bitumen recovery technology.

Experimental Procedure

The research on steam-thermal treatment (hereinafter referred to as experiments P1-P5) was carried out on a non-extracted crushed packed model of a reservoir. This had a length of 215 mm and a diameter of 30 mm (a bulk model was used since attempts to drill samples from a clay core led to its destruction), and in experiment P6 on a composite core model with a length of 100 mm and a diameter of 30 mm. A shorter column length is caused by an insufficient amount of material.

The researches were carried out on a filtration unit to simulate the process of heat-steam exposure, the scheme and details of the unit are described in [9,10,11], at a reservoir pressure of 0.8 MPa and a temperature of 45 °C.

In the first experiment, to assess the effect of temperature on the swelling of clays, cold and subsequently hot water were injected at a constant flow rate of 0.3 ml/min, steam was injected at a temperature of 200 °C with a constant flow rate of 1 ml/min; in subsequent experiments, only steam was injected. During the experiment, temperature and pressure were recorded. Experimental conditions are presented in table 1.

To determine the mineral composition, X-ray diffraction analysis (XRD) was carried out on a Bruker D2 Phaser X-ray diffractometer. The amount of each mineral phase was calculated from the intensity of the peaks in the diffractogram. The XRD results of the samples are presented in figure 1 and table 2.

Core sampling was carried out from oil-saturated intervals during test drilling of wells

Table 1

Characteristics for packed model in experiments P_1 - P_6

№	Injection agents	Absolute permeability, D		Content of clay minerals, % mass.
		Before injection	After injection	
P_1	1) Water 23 °C* 2) Hot water 100°C 3) Steam 200°C	0.6	1.5	8
P_2	Steam 200°C	3.54	0	28
P_3	Steam 200 °C	7.2	8.5	0
P_4	Steam 200 °C	3.84	4.64	4
P_5	Steam 200 °C	1.17	0	18
P_6	Steam 200 °C	0.0067	1.4	5

* sequential injection of agents

(50-110 m), with different clay content in the samples. Bitumen oil was obtained by extraction of crushed core in a Soxhlet apparatus with subsequent distillation of the solvent by rotary evaporator IKA RV10. Viscosity and SARA fractions for obtained bitumen oil were 2200 Pa·s at 25 °C; saturates - 28.8%, aromatics - 23.9%, resins - 39.4%, asphaltenes - 7.9%.

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Results and discussions

The samples can be conditionally divided into three groups, based on the content of clay minerals:

- 1) Highly clayey (1, 2) - clay content over 10%.
- 2) Moderately clayey (3, 4 and 5) - clay content 4-10%.
- 3) Carbonate cemented (6) - clay minerals are absent.

The XRD results show that the main clay minerals in the rock are kaolinite, micas, and clinocllore. The bulk of the rocks consists of quartz, microcline and albite, with clay and carbonate minerals acting as cement. Rare inclusions of pyrite are also found.

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Filtration experiment P_1 on the model of sample 3. Figures 2 and 3 show the temperature profile and pressure drop in the model.

During experiment P_1 it was found that with an increase in the temperature of the injected agent, the pressure drop on the model increases. There is no oil displacement during sequential injection of agents.

Filtration experiment P_2 on the model of sample 2 (fig. 4 and 5) show the temperature profile and pressure drop in the model.

Table 2

Mineral content in samples

Mineral/Sample number	1	2	3	4	5	6
Quartz	27	64	55	59	54	38
Microcline	20	5	23	21	15	31
Albite	18	2	10	-	7	9
Dolomite	16	-	2	8	4	10
Calcite	1	-	2	3	15	11
Barite	-	-	-	-	-	1
Pyrite	1	-	-	-	1	-
Kaolinite	4	7	2	2	2	-
Mica	4	21	6	2	3	-
Clinocllore	10	-	-	-	-	-

During experiment P_2 at steam injection, swelling of clays is observed (fig. 6), which led to an increase in pressure drop of more than 250 bar.

Filtration experiment P_3 on the model of sample 4 (fig. 7 and 8) show the temperature profile and pressure drop in the model.

During the P_3 experiment, there was no oil displacement from the model during steam injection. Pressure drop is 0.2 atm this is due to the absence of clays and the high permeability of the disintegrated packed model.

Filtration experiment P_4 on model 6. (fig. 9 and 10) show the temperature profile and pressure drop on the model in the P_4 experiment.

During the P_4 experiment, it was found that there is no oil displacement from the model during steam injection.

Filtration experiment P_5 on the model of sample 1 (fig. 11 and 12) show the temperature profile and pressure drop in the model.

During the experiment P_5 it was found that there is no oil displacement during steam injection.

Filtration experiment P_6 was conducted on a composite model of sample 5. Figure 13 and 14 show the temperature profile and pressure drop of the model. When injecting steam, oil displacement efficiency was 28%, with the oil displacement efficiency shown in figure 15. The experimental results are shown in table 3.

During the experiments, it was found that the

effect of steam on the model with a bitumen oil content of less than 2 % mass., is not effective. Therefore, for the purpose of oil recovery, a solvent based on aliphatic and polar fragments was selected and tested. Such a solvent is used as it contributes to the dissolution of resins and asphaltenes and an increase in bitumen mobility. To assess the degree of potential "compatibility", a drip test was carried out for the compatibility of the oil with the solvent.

Determination of the aggregated stability of the mixture obtained by oil filtration with a solvent was carried out in accordance with the ASTM D 4740-02 method.

To determine compatibility, the stains obtained experimentally were compared with a reference stain map (ASTM D 4740-02). All types of solvent mixtures tested were compatible.

To assess the efficiency of displacement of bitumen with oil saturation less than 2%, filtration experiments were carried out on the same models and conditions from experiments SW1-SW6. The dynamics of changes in pressure and oil displacement ratio are presented in figure 16.

In the SW_2 experiment the increase in the pressure drop exceeded 100 atm due to the high clay content during the injection of the solvent rim. The results of the filtration experiments carried out to displace bitumen by sequential injection of solvent and water are presented in table 4.

Fig.1. XRD analysis of core samples

Fig.13. Temperature history of each zone for the experiment P_6 Fig.14. Pressure drop in the experiment P_6 Fig.15. Oil displacement efficiency in the experiment P_6

Oil recovery information for experiments P_1 - P_6					Table 3
№ test	Core number	Oil saturation of the initial core, %	Oil volume in the initial core model, ml	Recovered oil volume, ml	Oil displacement efficiency, %
P_1	3	1.66	5.4	0	0
P_2	2	0.73	2.3	0	0
P_3	4	1.17	3.91	0	0
P_4	6	1.14	4.12	0	0
P_5	1	0.4	1.4	0	0
P_6	5	10.61	7.53	2.11	28

Fig.16. Pressure drop and oil displacement efficiency in experiments SW₁-SW₆

Table 4

Oil recovery information for experiments of sequential injection of solvent and water «SW₁- SW₆»

№ test	Core number	Recovered oil volume, ml	Oil displacement efficiency, %
SW ₁	3	3.67	68
SW ₂	2	0	0
SW ₃	4	2.78	71
SW ₄	6	2.68	65
SW ₅	1	0.85	61
SW ₆	5	4.64	61.5

Conclusions

Steam injection with a clay mineral content in packed model of more than 28% shows sharp increase in the pressure drop up to 250 bar and the absence of injectivity. At a clay content of 18% an increase in the pressure drop up to 100 bar is observed, which influenced the breakthrough of steam, forming a fracture, along which filtration continued with a minimum pressure drop. When the clay content is less than 10%, an increase in permeability and low pressure drop values are observed, which indicates the possibility of using thermal steam injection. Injection of cold water, hot water and steam into the studied rock samples (experiments P_1 , P_3 - P_6) with low bitumen content (<2% mass.) proved to be ineffective, as a result of which the technology of sequential injection of solvent and water was applied successfully (oil displacement efficiency 61-71%). It was found that steam injection was effective only in experiment P_6 (oil displacement efficiency 28%), where the study was carried out on a composite model with a high bitumen content and a clay mineral content of 5%.

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Оценка влияния содержания глинистых минералов на эффективность паротеплового воздействия для добычи битуминозных нефтей

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Реферат

В мировой практике при разработке битуминозных коллекторов применяется паротепловое воздействие, так как эта технология считается наиболее эффективной, но имеет ряд проблем при наличии глинистых минералов в породе. При контакте глинистых минералов с паром происходит их набухание, что приводит к уменьшению проницаемости коллектора в следствии чего конечная нефтеотдача снижается. В данной работе оценивается влияние содержания глинистых минералов на степень вытеснения нефти при паротепловом воздействии. В результате закачки пара в экспериментах с низкой начальной нефтенасыщенностью менее 2% отсутствует нефтевытеснение. Для извлечения нефти был опробован растворитель на основе алифатических и полярных фрагментов.

Ключевые слова: закачка пара; битумы; глинистые минералы; растворитель; вытеснение нефти.

Bitumlu neftlərin hasilatı üçün buxar istilik ilə təsirin effektivliyinə gilli mineralların tərkibinin təsirinə qiymətləndirilməsi

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Xülasə

Dünya təcrübəsində bitumlu kollektorların işlənməsi zamanı buxar-istilik ilə təsirdən istifadə olunur. Lakin bu texnologiya daha effektiv hesab olunsada, süxurda gilli minerallar olduqda bir sıra problemlər yaranır. Gilli minerallar buxarla təmasda olduqda onların şişməsi baş verir ki, bu da kollektorun keçiriciliyinin azalmasına gətirib çıxarır və nəticəsində son neftverimi aşağı düşür. Məqalədə gilli mineralların tərkibinin buxar-istilik ilə təsir zamanı neftin sıxışdırılma dərəcəsinə təsiri qiymətləndirilir. Buxarın vurulması nəticəsində ilkin neftlə doyma səviyyəsi 2% - dən aşağı olan eksperimentlərdə neftin sıxışdırılması baş vermir. Neftin çıxarılması üçün alifatik və polyar fraqmentlər əsaslı həlledici sınaqdan keçirilmişdir.

Açar sözlər: buxar vurma; bitumlar; gilli minerallar; həlledici; neftin sıxışdırılması.