Thermal EOR

International Workshop «Thermal Methods for Enhanced Oil Recovery: Laboratory Testing, Simulation and Oilfields Applications»

Baku, Azerbaijan, November 3-5, 2022

1804

ADNSU

BOOK OF ABSTRACTS
V International Workshop «Thermal Methods for Enhanced Oil Recovery: Laboratory Testing, Simulation and Oilfields Applications» ThEOR2022

November 3 - 5,
Azerbaijan State Oil and Industrial University, Baku, Azerbaijan

Content

STEAM FLOODING, CYCLIC STEAM STIMULATION, STEAM ASSISTED GRAVITY DRAINAGE (SAGD), INCLUDING SOLVENT-AIDED PROCESSES

Methods of Heavy Oil Production from Wells on the Western Slope of the South Tatar Arch

Isaev A.A.
Sheshmaoil Management Company LLC, Russian Federation
*Corresponding author: isaeff-oil@yandex.ru

Keywords: heating of the reservoir; steam injection; heat-resistant equipment; viscosity; viscometer

Abstract: The article presents the results of cyclic steam stimulation of the Bashkirian stage. The curves of downhole and wellhead temperatures and pressures are shown. The steam was injected by two portable steam units operating in parallel. The maximum achieved downhole temperature was 200 ºC while the temperature at the wellhead was 260 ºC, thereby the heat loss was 23%. Heat losses can be reduced by thermal insulation of the wellhead piping. Heating the reservoir has significantly increased the viscosity of the water-in-oil emulsion from 300 cSt to 1200...1400 cSt, because, at first, the viscosity decreased near the bottomhole, but further extraction of heated oil resulted in that highly viscous oil located far from the bottomhole was dragged towards the bottomhole.

The article provides the results of heat loss identified under test bench conditions and immediately on site at the well No. 8666 of JSC Kondurchaneft. To reduce costs and improve performance, a number of technical improvements have been developed for the set of heat-resistant equipment: expansion of the inner diameter of the TK 114-73 bushing assembly from 59 to 62 mm; making grooves on the couplings of Vacuum Insulated Tubings (VIT) for cable routing; development of bottom anchor housing for locking the bottom anchor NM-73/60 and cable entry; reducing the number and sizes of devices comprising the wellhead assembly. The bench tests showed that the average heat loss by VIT amounted to 12%, heat loss by VIT in the well was 17%.

As an analogue option to VIT, Sheshmaoil LLC has developed a unit with insulated hollow rods. The implementation of a special pump on a number of wells made it possible to increase the time between failures and the time between repairs. Steam is pumped via hollow rods.

A viscometer (fig.1) based on the measuring principle by Höppler is used to measure the actual dynamic viscosity of heavy oil in wells, i.e. the viscosity is determined by the time required for a ball to fall under gravity through a sample-filled tube that is inclined at an angle. The fluid (emulsion) is measured at the actual fluid temperature.

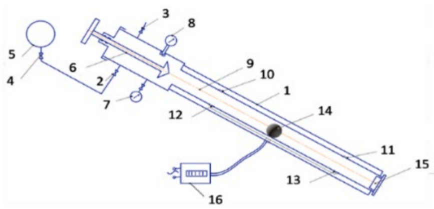


Fig.1. Viscometer

Application of Geochemical Methods for Investigating Natural Bitumen Properties of Superviscous Oil Deposits Developed Using SAGD Technology to Optimize the Position of Steam Injection Points and Pump Location, Republic of Tatarstan, Russia

Maria Shipaeva[a,b,*], Vladislav Sudakov[a], Marat Amirkhanov[c]
[a]Kazan Federal University, Institute of Geology and Petroleum Technologies, Russia
[b]Geoingicator company, Russia
[c]Tatneft PJSC, Russia
[*]Corresponding author: mariasipaeva@gmail.com

Keywords: SAGD, geochemistry; biomarkers; oil field development; superviscous oil.

The global reserves of high-viscosity and extra-viscous oil are known to be approximately 640 billion tons, resources of Russian Federation in this category are 75 billion tons. In addition, about 70% of it is concentrated in the Volga-Ural region (mainly in the Republic of Tatarstan). Currently, superviscous oil production is carried out in the Republic of Tatarstan using a number of technologies, including the cyclic steam stimulation technology and steam assisted gravity drainage (SAGD) technology. At present, there are 24 superviscous oil deposits of the Sheshminsk horizon are put into production, 15 deposits are at the stage of operational drilling and preparation for commercial development. Since 2017, geochemical monitoring technology has been used at four fields as they are put into commercial operation. The technology is implemented by taking core samples by depth from all exploration wells in the number of at least 5 samples for each well, extraction of hydrocarbons, GCMS analysis and building a geochemical model of the deposit. After the SAGD wells are commissioned, oil samples are taken from each producing well with a time lag of one quarter, and GCMS analysis and biomarker studies are performed for oil-oil correlation purposes. An assumption is made about the current position of the steam chamber and the drainage area. Then, after shifting the steam injection points or pump location along the wellbore (its length is more than 1 km) for uniform warming, samples are taken again to assess the displacement of the steam chamber. These operations continue for several years for more efficient oil recovery. Despite the regional unity of deposit localization, our results show us that the location of studied wells at different depths affects different properties in each geochemical model. By comparing the oil production data for 2015 and 2022, we see a 9.5-fold increase in the volume of resources extracted in 2021, which is also possible due to the geochemical monitoring technology used since 2017.

Numerical Simulation of Thermo-Hydro-Mechanical Processes Accompanying Steam-Assisted Gravity Drainage Method

Anastasiia A. Kostina *, Maxim S. Zhelnin, Oleg A. Plekhov
Institute of continuous media mechanics of the Ural branch of Russian academy of science, Russia
* Corresponding author: kostina@icmm.ru

Keywords: Multiphysics Problems; SAGD; Finite-element analysis; THM models

Most studies devoted to steam-assisted gravity drainage (SAGD) method are concentrated on thermal and filtration processes. However, an increase in the temperature of oil reservoir induces thermal expansion of solid skeleton and occurrence of volumetric strains activated by thermal front propagation. This leads to the evolution of porosity with accompanying change in the permeability of the reservoir. Variation of the pore pressure can affect effective stress of solid skeleton and, therefore, provide contribution to the overall change in the stress-strain state of the formation. Accordingly, accurate description of SAGD requires development of coupled models which take into account complex interaction between thermal, mechanical and filtration processes.

The aim of this work is to develop a coupled thermo-hydro-mechanical model of SAGD and an algorithm of its computer implementation for the 3D case. Thermo-hydraulic part of the model includes mass balance equations of the three-phase flow (steam, water and oil) and energy balance equation accounting for convective heat transfer and phase transition. The mechanical part of the model includes the momentum balance equation, geometric relation, constitutive equations for elastic and inelastic strains. State equations for porosity and absolute permeability are added to the model to ensure coupling between mass transfer and mechanical processes. The proposed model was adapted for solution in the Comsol Multiphisics Software. The developed algorithm was based on the pressure-saturation formulation with a total velocity. The equations of the model were implemented using Weak Form PDE interface, Heat Transfer Module and Structural Mechanics module.

Verification of the proposed model was carried out by numerical simulation of two different laboratory experiments published in literature. The first one compares steam chamber development in prototypes of homogeneous reservoir and reservoir with several impermeable barrier layers. The second one considers SAGD in heterogeneous reservoir with non-uniform permeability. After that, the model was applied for the explanation of the thermal monitoring data obtained by the observation wells at one of the sites of Yarega oil deposit (Russian crude oil deposit in Komi Republic). Also, the field-scale studying of the surface heave effect, which can be dangerous for the environment was performed, and effect of the non-uniform heating of the reservoir was investigated. Therefore, the developed model can be used to analyze performance of a new reservoir or to increase oil production at an existing one.

The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation (theme No. 122012400263-7).

Cyclic Steam Stimulation Technology Simulation on Hydrodynamic Model

Mukhtar Shakenuly Shaken*
"KMG Engineering" LLP, Kazakhstan
*Corresponding author: shaken_m@kaznipi.kz

Keywords: high viscous oil reservoir; cold production; steam-assisted gravity drainage; thermal methods of oil production; enhanced oil recovery.

Due to the decrease in "easy" oil reserves, oil companies are focusing on "hard-to-recover" reserves, in particular, high-viscosity oil reservoirs. Shallow oil reservoirs are mainly concentrated in the Cretaceous horizons, in the western region of the country, along the Caspian coast. One of them is a high-viscosity oil reservoir, consisting of three Cretaceous horizons. The average viscosity of oil in reservoir conditions is around 746.7 cP. The current achieved oil production is only 5% of the initial recoverable reserves, and designed oil recovery factor is 38% and implies the full-scale application of thermal methods of EOR.

The objective of this work was to choose the most suitable thermal method of EOR and to assess the prospects of applicability with the calculation of economic feasibility. Considering the geological features of the reservoir, the cyclic steam stimulation was chosen as the optimal method to increase oil recovery. In order to assess the expediency of this technology, was initiated project on thermal modeling the technology based on the current geological and hydrodynamic model of the field, using the results of laboratory studies, calculations were performed on imagined horizontal wells, and carried out the analysis of technical and economic efficiency.

To simulate the development using the CSS technology, 6 horizontal wells are placed in the model along the bottom of the formation. The steam injection temperature is assumed to be 250 ° C, steam dryness is 0.5. Steam injection for a group of wells with CSS was accepted for 3 wells simultaneously for 2 weeks, then 1 week for impregnation, followed by launching into production for ~10 weeks. As soon as the steam generator finishes pumping in the first 3 wells, it switches to pumping on the next three wells.

According to the results of calculations on the hydrodynamic model, the production rates using the technology of cyclic steam stimulation in horizontal wells are 30% higher than the production rates of "cold production", and the difference in accumulated oil production over 5 years will be 20–30%. The use of CSS technology allows additional exploitation of the horizontal wells' potential.

To calculate the economic efficiency of the implementation of CSS technology, the estimated costs of the project were used (drilling horizontal wells, purchasing a steam generator unit, infrastructure, and others). The profitability index of the project for 5 years in comparison with "cold production" (capital costs only for drilling 6 horizontal wells) are 0.77 and 0.92, respectively.

In view of the positive technological effect, further research is necessary to clarify the current technological assessment of the project, which is economically feasible either with a decrease in capital costs by 34%, or with an improvement in technological efficiency by 21%.

Experimental And Numerical-Simulation Study of Oil Recovery by Steam-CO_2 Injection in Fractured Carbonate Porous Media

Octavio Cazarez-Candia*, Pedro F. Aguilar-Gastelum, Elizabeth Cervantes Flores
Instituto Mexicano del Petróleo, Eje Central Lázaro Cárdenas 152, C.P. 07730, Del. Gustavo A. Madero, Ciudad de México, México.
* Corresponding author: ocazarez@imp.mx

Keywords: Steam-CO_2 injection, rock dissolution, numerical simulation, thermal expansion, experimental study.

In the Steam-CO2 injection process for oil recovery from carbonate reservoirs, the dissolved carbon dioxide reacts with water and dissociates into a bicarbonate ion and a hydrogen ion. In turn, the bicarbonate ion reacts with the calcium carbonate of the rock leading to its dissolution. This dissolution could modify the permeability and porosity affecting the oil recovery process. In this work, heavy oil recovery experiments were carried out for the steam-CO2 injection process in fractured and homogeneous systems with noncarbonate and carbonate rocks. It was observed that the recovery factor was higher for carbonate systems than for the noncarbonate ones in both cases fractured and homogeneous systems.

To explain why the recovery factor was higher for carbonate systems, rock dissolution experiments were conducted to demonstrate that rock dissolution occurs when CO2 is injected with the steam. It was found that the permeability and porosity increase up to 110 mD and 0.59%, respectively, due to the rock dissolution, which has a positive effect getting an increase of 22% in the recovery factor. Moreover, an oil recovery experiment was carried out for a hot water-CO2 injection in a carbonate fractured system to confirm such a positive effect, getting an increase of 30.47% in the recovery factor (Figure 1).

Additionally, the numerical simulations of the oil recovery experiments were carried out and used to study the optimal CO2/steam ratio to get the maximum oil recovery. It was found that such a ratio should be 8.

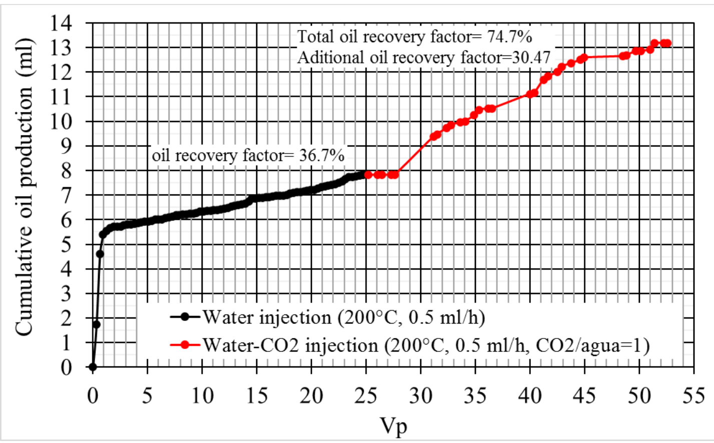


Figure 1. Cumulative oil production and oil recovery factors for the hot-water and hot-water-CO_2 injection processes in a carbonate system.

Application of Thermal Methods to Decrease Water Leakage on a Circular Heavy Oil Water Drive Reservoir.

Novruzova H. Sudaba, Mangushev R. Rufat*, Gadashova Elmira
Azerbaijan State Oil and Industry University, Azerbaijan
* Corresponding author: rufat.mangushev@gmail.com

Keywords: circular reservoir; heavy oil; water zone; feeding contour; water loss; hydraulic resistance; initial pressure drop.

Abstract. In this article the authors seek to solve a hydrodynamic problem for a circular heavy oil reservoir. Core of the problem is in excess injected water loss to the formation during the waterflooding operations to increase oil recovery factor.

Calculation formulae for determination daily volume of water pumped into the reservoir through injection wells, for production rate of oil wells and for water loss volume into the water bearing formation zone have been derived and implemented by the authors for both waterflooded and thermally flooded reservoir performances.

Initial estimation of the injected water loss into formation has been given. These calculations indicated that 46.91% or roughly half of all the water injected into the formation to perform waterflooding is lost to the said formation without providing its intended effect of increasing oil recovery.

Using the derived formulae, the authors have performed numerical calculations which demonstrate that injection water loss volume decreases as a result of thermal influence from 46.91% to just 3.5% on the given circular heavy oil water drive formation, oil production rate increases drastically, which in turn increases considerably oil recovery coefficient.

The desired effect of increased oil recovery and mitigation of excess injected water losses can be achieved via application of thermal methods to the formation.

The authors offer an additional arrangement for creation of a low permeable ring stripe in the water zone of the formation, via wastewater injection which deserves special attention.

Impact of Methane Injection on SAGD Performance. Analysis of Laboratory Survey and Field Scale Simulation Results

Regina E. Safina [a]*, Sergey A. Usmanov [a], Allan A. Rojas [a], Ilgiz F. Minkhanov [a], Vadim K. Derevyanko [a], Aidar R. Tazeev [a], Mikhail A. Varfolomeev [a], Vladislav A. Sudakov [a] , Marat I. Amerkhanov [b], Fanil M. Akhmetzyanov [b]
[a] Kazan Federal University, Russia
[b] PJSC «Tatneft», Russia
* Corresponding author: safinar101@gmail.com

Keywords: SAGD; super-viscous oil; numerical simulation; non-condensable gas

SAGD is a successful thermal recovery technique, applied in Permian super-viscous oil deposits in the Republic of Tatarstan. Despite its proven efficiency, SAGD remains an energy-consuming technique and thus results in considerable GHG emissions. In one of the SAGD modifications a non-condensable gas is added to the injected steam to maintain pressure in the steam chamber. Methane is used as the main soluble non-condensable gas in oil reservoirs. Being lighter than steam, methane tends to accumulate in the upper part of steam chamber and reduce heat losses to the overburden rock. In addition, the ascending gas produces the gravity effect on oil, dragging it down towards the producer well.

However, heat losses on the edges of the steam chamber (due to excess non-condensable gas) and risk of chamber collapse (due to reduced steam partial pressure) require careful estimation of the amounts of planned injected gas in accordance with the current size of the steam chamber. The numerical model was used to investigate the impact of different volumes of injected methane on SAGD process.

Physical-chemical effects of the process including the methane diffusion and probability of asphaltenes precipitation should be considered in numerical models and require laboratory studies for a specific oil including oil displacement experiments by methane and steam. For that reason, steam and methane co-injection were conducted, analyzed and reproduced on one-dimensional physical model.

Field scale numerical simulation results show the evidence that the modification of SAGD technology could become ineffective with continuous steam and methane co-injection or with cycling co-injection of steam and steam/methane with a ratio less than 2/1. Considering the technique limitations, numerical simulation allows to choose the best scenario (in terms of optimal volume and best well candidates) where methane, as an EOR agent in steam co-injection, shows better effectivity than as a fuel for water to steam conversion.

Experience of well strategy oprimization on example of Boca de Jaruco carbonate bitumen reservoir

Iaroslav O.Simakov [a*], Alexander I. Volik [a*], Aleksey V. Solovev [b*], Georgi V. Sansiev [b*]
[a] JSC VNIIneft, Russia
[b] JSC Zarubezhneft, Russia
[*] Corresponding author: ysimakov@vniineft.ru; yaroslav.s.olegovich@gmail.com

Keywords: Bitumen, steam cycling stimulation, horizontal well, steam-oil ratio (SOR)

Since 2015, Zarubezhneft JSC has been testing the steam-thermal effect on carbonate formations saturated with native bitumen at the pilot area of Boca de Jaruco field, reservoir M (Republic of Cuba).

Oil of deposit M is one of the heaviest in the world in terms of viscosity and density: viscosity in reservoir conditions is 36000 mPa*s, density is 1021.7 kg/m^3. The reservoir rock is a fractured-porous carbonate with a dense system of fractures. Combination of geological and physical characteristics makes this object unique in the world practice of using thermal methods.

At the first stage of formation M exploitation (2015-2019), the production was provided by vertical wells. During this time, commercial oil inflows were obtained: oil flow rates up to 50 tons/day, SOR reduction down to 5 t/t during the best cycle.

In 2020-2021 4 horizontal wells were drilled as part of the second stage of pilot work. Horizontal wells are more efficient than vertical wells, primarily due to involved bituminous rocks volume increase. On the other hand, to implement this sweep, larger volumes of steam injection are required than in vertical wells. In accordance with this logic, the volumes for the first steam treatments were selected.

The main task of this report is to show practice concerning with changing well operation strategy allowing to reach deacreasing of steam-oil ratio for the horizontal wells.

Early 2021, due to the negative results of the first CSSs on horizontal wells, a decision was made to change the operation strategy. The new strategy concerned the choice of steam injection volumes in cycles and was based on the principle of gradually increasing injection from smaller volumes to larger volumes (mini-CSS strategy). It was assumed that this approach, due to gradual capillary imbibition, should ensure the consistent involvement of massive unheated formation volumes, as well as increase the fraction of condensate returned from the total mass of injected steam. Key performance indicators must be related with the gradual decrease and subsequent stabilization of the SOR at a cost-effective level with a gradual increase in steam injection in cycles (due to a corresponding increase in oil production).

Since 2021 to present the achieved results of the pilot project confirmed the feasibility of choosing the mini-CSS strategy. From the first mini-cycles to the present, there has been a decrease in SOR for all horizontal wells, a record value of 4 t/t in the cycle has been reached. Based on the results obtained, an assessment of the prospects for horizontal wells during the period of business planning was implemented.

Taking into account the presence of a dense system of fractures and small distances between wells (30-100 m), special attention is paid for monitoring and control of wells.

New technologies for treatment of the formation bottomhole zone using thermochemical influence

Bolotov A.V*., Anikin O.V., Minkhanov I.F., Varfolomeev M.A.
Department of Petroleum Engineering, Kazan Federal University, Russia
* Corresponding author: highpress@gmail.com

Keywords: thermochemical treatment; bottomhole zone; physical 1-D modeling

The most of the world's major fields in the final stages of development requires new intensive methods of improving oil recovery. In recent decades, interest in in-situ heat generation has increased dramatically due to the injection of thermochemical fluids as a complex impact on well productivity to clean the bottomhole zone of the formation and intensify oil-saturated zones with impaired porosity and permeability properties. Rational use of this method in the well requires preliminary determination of the efficiency of injection of such fluids on core models of different reservoir types under reservoir conditions of the field. In this work well known liquids such as binary mixtures and hydrogen peroxide having a high thermo-chemical potential have been tested in physical 1-D modeling by injecting these fluids through rock with temperature and pressure rise recording. Based on the obtained data during filtration experiments, it was shown that hydrogen peroxide injection through a disintegrated core model leads to partial cleaning from immobile oil and heavy deposits included in the rock, when the model is heated to 180-240 °C because of the decomposition of hydrogen peroxide with a catalyst and under the catalytic influence of the rock. During tests using a thermos-chemical fluid including a solution of ammonium nitrate with nitrites of alkali metals, various thermobaric effects were observed when injected into a composite core model with varying reaction initiators and the addition of thermo-salt-resistant surfactant. The injection of these mixtures showed the possibility of reaching high temperatures in the initial zone and further advancement of the thermal front along the model through the porous medium. Thereby the results of studies can provide a preliminary assessment of the effectiveness of thermochemical treatment in fields operated at a late stage of development for cleaning the bottomhole zone from deposits, reducing the skin factor and increasing well productivity.

Mathematical Modeling of Cyclic-Steam Stimulation in the Reservoir-Well System

Tatiana Nikolaevna Kovalchuk*, Alexander Yanovich Gilmanov, Alexander Pavlovich Shevelev
University of Tyumen, Russia
* Corresponding author: t.n.kovalchuk@mail.ru

Keywords: cyclic steam stimulation; short-term dynamic temperature studies; optimization; injection time; mechanics of multiphase systems

Cyclic steam stimulation (CSS) is one of the most common enhanced oil recovery methods for heavy oil production and is characterized by the highest thermal efficiency. One of the problems is the successful transport of heat carrier to the bottom of the well. The use of the technology of short-term dynamic temperature studies allows to monitor the dynamics of temperature changes along the entire length of the well.

Mathematical modeling of CSS, determination and optimization of the main technological parameters allows to increase the effectiveness of the impact several times. Therefore, the goal was set in the work to create a methodology that will allow rapid assessment of technological parameters using the data of the technology of short-term dynamic temperature studies for determination of th optimal times for heat carrier injection, steam soak and the stage of oil production.

The integral approach to the description of the process of CSS is based on the equations of mechanics of multiphase systems. In particular, the authors have developed a model of the dynamics of the heated area under cyclic steam stimulation. The authors have written a program code to solve the problems. In this case, numerical methods were used to solve systems of equations. For the first time, the authors proposed an integrated approach linking the problems of transporting the heat carrier and determining the optimal parameters of reservoir treatment.

Thus, the times of heat carrier injection, steam soak and the oil production stage were determined, considering the decrease in steam quality when the heat carrier moves along the wellbore. The authors determined functions for the distribution of steam temperature, pressure, velocity and steam quality depending on depth. The paper obtained temperature distributions in the borehole walls and in the rock. The value of the heat transfer coefficient of the rock was refined, considering the temperatures between the layers of materials of the well, water and rock.

Optimization of Steam-Thermal Treatment Technology in Relation to The Strelovsky Field Using Aquathermolysis Catalysts

Mohammed O. Ali [a]*, Irek I. Mukhamatdinov [a], Olga V. Slavkina [b] and Alexey V. Vakhin[a]
[a] Kazan Federal University, Russia
[b]LLC «RITEK»,
* Corresponding author: omarmohammed047@gmail.com

Keywords: catalyst; steam-thermal treatment; heavy-oil; aquathermolysis; catalytic upgrading

In recent years, it has been observed that the reserves of light oil have decreased and the reserves of heavy oil have increased in the world, reaching more than 30% of the total oil reserves. The high viscosity of heavy oil is due to the fact that it contains such heavy compounds as asphaltene and resin. Heavy oil is characterized by its high viscosity, which leads to a low efficiency of using traditional extraction methods. Usually, for the development of heavy oil fields, steam-thermal treatment methods are used to lower the viscosity and thus enhance the oil recovery.

In this work for testing, a laboratory simulation of the steam-thermal treatment of high-viscosity oil from the Strelovsky field was carried out without and with the addition of a solvent for asphalt-resinous-paraffin deposits to the system and catalyst, which is an oil-soluble catalyst precursor - iron tallate. Experiments were carried out at different temperatures of 250 °C and at different durations of exposure (24, 48, 72, and 96 hours).

According to viscometry data, the results of viscosity determination indicate that, as well as after aquathermolysis at a temperature of 250 °C and 48 hours, the initial oil and the product of non-catalytic aquathermolysis have a viscosity measured at 20 ° C above 4,700 mPa·c. Compared to the control experiment, the viscosity of oil with iron tallate and solvent, measured at 20 °C, is reduced by more than 3 times. The catalyst contributes to the destruction of associated complexes of resin molecules, thereby affecting the reduction of the viscosity of the oil. The action of the disperser is that it dissolves directly in the oil, then the alkaline blocks of surfactants are introduced into the paraffin deposits at the time of the phase transition to a solid state and crystallize with them. The results of gas chromatography - mass spectrometry revealed a decrease in the content of hydrocarbons from C19 to C30 with a simultaneous increase in n-alkanes from C12 to C19 compared with the control experiment without a catalyst and solvent, which confirms the effect of the catalyst on the intensification of cracking of C-C bonds.

Direct Hydrogen Production from Extra Heavy Crude Oil under Supercritical Water Conditions using a Catalytic (Ni-Co/Al_2O_3) Upgrading Process

Richard Djimasbe [a*], Ildar R. Ilyasov [b], Michael Kwofie [a], Mohammed A. Khelkhal [a], Dmitry A. Emelyanov [a], Ameen A. Al-muntaser [a*], Muneer A. Suwaid [a*], Mikhail A. Varfolomeev [a*]

[a] Department of Petroleum Engineering, Kazan Federal University, Kazan 420008, Russia;

[b] Alexander Butlerov Chemistry Institute, Kazan Federal University, Kazan 420008, Russia;

[*]Corresponding authors: Richard Djimasbe: richarddjimasbe@yahoo.fr; Mikhail A. Varfolomeev: vma.ksu@gmail.com; Muneer A. Suwaid: Suwaidmuneer@gmail.com; Ameen A. Al-Muntaser: almuntaser.ameen@gmail.com

Keywords: extra heavy oil; supercritical water; aquathermolysis, catalysts, nickel, cobalt, aluminum oxide, EOR, hydrogen.

The generation of hydrogen from unconventional oil is expected to increase significantly during the next decade. It is commonly known that hydrogen is an environmentally friendly alternative fuel, and its production would partially gap energy market requirements. However, developing new cheap catalysts for its production from crude oil is still a challenging area in the field of petroleum and the petrochemical industry. This study presents a new approach to synthesizing and applying promising catalysts based on Ni, Co, and Ni-Co alloys supported by aluminium oxide Al_2O_3 for hydrogen production from extra heavy crude oil in the Taha oil field (China), in the presence of supercritical water (SCW). The obtained catalysts were characterized by scanning electron microscopy (SEM), Brunauer-Emmett-Teller (BET) surface area analysis, Transmission electron microscopy (TEM), and, X-Ray diffraction analysis (XRD). The obtained XRD data showed 3.22% of Co^{2+} in Co/Al_2O_4, 10.89% of Ni^{2+} in Ni/Al_2O_4 catalysts, 1.51% of Co^{2+} and 2.42% of Ni^{2+} in the Ni-CoAl_2O_3 bimetallic catalyst. The BET measurements of the obtained catalysts showed a surface area ranging from 3.04 to 162 m²/g, an average particles size ranging from 0.037 to 0.944 µm, and micropore volumes ranging from 0.000377 to 0.004882 cm³/g. The thermal, SCW and catalytic upgrading processes of the studied samples were conducted in a discontinuous autoclave reactor for 2 hours at a temperature of 420°C. The obtained results revealed that thermal upgrading yielded 1.059 mol. % of H_2, SCW led to 6.132 mol.% of H2 meanwhile the presence of Ni-CoAl_2O_3 provided the maximal rate of hydrogen generation with 11.783 mol.%. Moreover, Ni-CoAl_2O_3 and NiAl_2O_3 catalysts have been found to possess good affinity and selectivity toward H_2 (11.783 mol.%) and methane CH_4 (40.541 mol.%). According to our results, the presence of SCW increases the yield of upgraded oil (from 34.68 wt.% to 58.83 wt.%) while decreasing the amount of coke (from 51.02 wt.% to 33.64 wt.%) due to the significant amount of hydrogen generation in the reaction zone, which reduces free radical recombination and thus improves oil recovery. Moreover, the combination of SCW and the synthetized catalysts resulted in a significant decrease in asphaltenes content in the upgraded oil from 28% to 2% as a result of good redistribution of hydrogen over carbons (H/C) during the upgrading processes, where it increased from 1.39 to 1.41 in the presence of SCW and reached 1.63 in the presence of Ni-CoAl_2O_3 catalyst. According to the XRD results of the transformed form of catalysts ($CoNi_3S_4$) after thermal processing promotes heteroatom removal from extra heavy crude oil

via oxidative and adsorptive desulfurization processes. These findings contribute to the expanding body of knowledge on hydrogen production from in-situ unconventional oil upgrading.

Acknowledgments: «This paper has been supported by the Kazan Federal University Strategic Academic Leadership Program (PRIORITY-2030)»

Efficiency Analysis of Super-viscous Oil Recovery by In-situ Catalytic Upgrading in Cyclic Steam Stimulation. From Laboratory Screening to Numerical Simulation

Ilgiz F. Minkhanov [a], Alexander V. Bolotov [a], Regina E. Safina [a]*, Aidar R. Tazeev [a], Vladislav V. Chalin [a], Alexey V. Vakhin [a], Irek I. Mukhamatdinov [a], Sergey S. Sitnov [a], Rezeda E. Mukhamatdinova [a], Mikhail A. Varfolomeev [a], Sergey A. Usmanov [a], Yaroslav O. Simakov [b], Evgeniya A. Nikitina [b], Alexey V. Soloviev [c], Georgiy V. Sansiev [c], Kirill A. Dubrovin [c], Andrey V. Sharifullin [a], Danis K. Nurgaliev [a]

[a] Kazan Federal University, Russia

[b] JSC «VNIIneft », Russia

[c] JSC «Zarubezhneft», Russia

[*] Corresponding author: safinar101@gmail.com

Keywords: catalytic upgrading; super-viscous oil; numerical simulation; catalytic aquathermolysis

The worldwide conventional crude oils are significantly depleted, but conventional oil makes up only around 30% of total reserves. Thus, unconventional oils (high viscous, super viscous oil and bitumen) are becoming more economically attractive to extract and refine. In terms of super viscous oil recovery, in-situ catalytic upgrading in conjunction with steam-based technologies offer potentially higher recovery levels and lower environmental impact than standalone thermal EOR methods.

This article describes a method of predicting super-viscous oil deposit development performance by catalytic aquathermolysis process in reservoir scale based on laboratory testing and numerical simulation. The effect of catalytic oil upgrading is expressed in non-instantaneous reduction in oil viscosity and increase in sweep efficiency with catalytic upgrading. The kinetics of an oil upgrading reaction and dependance of residual oil saturation on the degree of oil upgrading, used in a thermal numerical simulation were based on laboratory testing results, and their matching on the basis of 0-D (batch reactor experiments) and 1-D (tube tests) conceptual models.

Field scale numerical simulation resulted in dependance of catalytic upgrading efficiency on the uniformity of well temperature profile, presence of residual oil and reservoir properties at the effective wellbore radius. It is shown that the effect of catalytic upgrading on a CSS well is determined not only by physical and chemical changes in oil composition but also by adsorption properties of the catalyst itself, heating the wellbore region and matrix and fracture interaction in reservoir. According to simulation results, choosing an optimal catalytic volume and injection scenario allows the recovery of up to 25% of additional oil, that reveals good perspectives of improving steam-based technologies by in-situ catalytic upgrading.

IN-SITU COMBUSTION (WET AND DRY COMBUSTION)

Effect of calcite and dolomite on crude oil combustion characterized by TG-FTIR

Mustafa Abaas [*], Dmitrii A. Emelianov, Kristina A. Ariskina, Mikhail A. Varfolomeev[*]
Department of Petroleum Engineering, Kazan Federal University, Russia
[*]Corresponding author: vma.ksu@gmail.com; Mustafa Abaas: mustafa988@yahoo.com

Keywords: enhanced oil recovery, in-situ combustion, crude oil, combustion, calcite, dolomite

In-situ combustion (ISC) is a significant thermal method for enhanced oil recovery (EOR) for heavy crudes (heavy oil and bitumen, etc.). Basically, in ISC processes, air (or oxygen-enriched air) is injected into reservoirs to initiate a combustion reaction of oil in place. Under a continuous air injection, a combustion front is built, which displaces oil towards production wells by a combined displacement process of gas drive (combustion gases), hot water flooding, steam drive. The combustion process of oil in reservoir involves a complicated physical chemistry process including chemical reactions, heat transfer, and mass transfer, etc., in oil/gas/ water/rock system. Rocks plays an important role in this process.

The purpose of this work is to investigate the influence of dolomite and calcite (main carbonate minerals) on the combustion process of crude oil using TG-FTIR.

This study is aimed at studying the influence of calcite and dolomite on crude oil combustion using TG-FTIR technique. According to the TG-DTG curves and the released gaseous products, the entire combustion process of crude oil can be divided into three regions: low temperature oxidation (LTO), fuel deposition (FD) and high temperature oxidation (HTO). The presence of calcite or dolomite significantly promoted the continuity of reactions, thus resulting in a smooth transition from LTO to FD, and further to HTO. Specifically, the explicit boundary between LTO and FD disappeared, the reaction of fuel formation started in the later stage of LTO, and the FD process was also partly merged with HTO reaction into one reaction region, even the simultaneous occurrence of FD and HTO reactions was observed for calcite. In general, calcite and dolomite have distinct catalytic effects on crude oil combustion. Their existence made fuel deposition and its combustion easier by significantly reducing the activation energy (mainly in FD stage and the beginning of HTO stage) from about 250 to 450 kJ/mol to 150–225 kJ/mol, which thus leads to a more continuous FD-HTO process. Calcite has a superior catalytic effect than dolomite as it achieved lower values of activation energy with smaller fluctuation (maximum 175 and 225 kJ/mol for calcite and dolomite, respectively). These results indicate that the presence of calcite and dolomite (especially calcite) is favourable for accelerating crude oil combustion reaction in in-situ combustion (ISC) process.

This work has been also performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

Application of in situ combustion for development of hydrogen generation technology in the reservoir

Aysylu Askarova*, Pavel Afanasiev, Alexey Smirnov, Evgeny Popov, Alexey Cheremisin
Center of Petroleum Science and Engineering, Skolkovo Institute of Science and Technology, Russia
*Corresponding author: A.Askarova@mail.ru

Keywords: hydrogen generation, in situ combustion, catalytic methane conversion, gas fields, kinetic reactions

Currently, hydrogen is an environmentally friendly and promising alternative fuel, and its generation can significantly cover the gap in energy market demand. However, the generation of "green" hydrogen remains a challenge. Catalytic methane conversion (CMC) technology realized in situ can become a new low-carbon, cost-effective method for hydrogen production. During this process, hydrogen can be generated in situ from fossil fuels, with simultaneous disposal of greenhouse gases. The presence of a catalyst and in-situ combustion due to air injection is required to increase and maintain the high temperatures inside the reservoir. This research investigates two laboratory experiments with two different oil saturations to study this technology using in situ combustion (ISC) under reservoir conditions. These experiments were performed using core and oil samples from the same reservoir to examine the mechanisms and patterns of the in situ hydrogen generation process.

The first experiment was performed on the samples with low initial oil saturation (10 %), where residual oil saturation serves as a fuel for the initiation of ISC and consequent hydrogen generation. The experiment consisted of four parts, with different regimes and operational parameters: forward ISC of oil, steam methane reforming (SMR) at 450 ºC and 8.9 MPa, SMR at 550 ºC and 8.9 MPa, SMR at 550 ºC and 2.3 MPa. The combination of these processes has led to the generation of hydrogen and methane conversion rates up to 40% (during the combustion stage) but low hydrogen yield, possibly due to the side reactions.

The second experiment of ISC was performed on the samples of a high-viscosity oil reservoir with higher initial oil saturation (50-60%) and altered permeability. The goal was to confirm the assumption on the process of coke gasification as the primary source of hydrogen generation and to select the optimal conditions for maximum hydrogen yield. Thus, the experiment was conducted on the core model with altered permeability to obtain the areas with coke after combustion front propagation. Optimal operational parameters for air and water injection rates were determined.

Both experiments displayed a similar amount of hydrogen in the 1-3 percent range, possibly due to coke gasification reactions. Obtained temperature profiles, as well as gas chromatography results, indicate that some portion of coke was formed and later reacted with steam during the second stage of cyclic in situ combustion. Also, an irreversible reduction of oil viscosity, density, sulfur, and asphaltenes content was achieved within the experiment. The influence of catalyst and generated hydrogen on oil quality is one of the additional positive effects of in situ hydrogen generation. This technology can be further applied scaled to the pilot projects after careful determination of the optimal conditions of hydrogen generation and verification of the kinetic model of hydrogen generation reactions during numerical simulations.

Tracking In-situ Combustion Front using Geophysical and Geomechanical Data

Mohammad Bazargan [a], Anthony R. Kovscek [b]
[a] Currently at Chemical and Petroleum Engineering Department, Sharif University of Technology, Iran
[b] Energy Resources Engineering Department, Stanford University, US
[*] Corresponding author: mbazargan@sharif.edu

Keywords: In-Situ Combustion, Front Tracking, Geophysics, Acoustic Emission, In-SAR

As much of a challenge a thin high-temperature combustion front is for simulations, it carries valuable information to be detected using geophysical tools and geomechanical analysis. We calculated that about 500-2000 psi local stress, depending on the rock properties, is caused at the combustion front. This stress distributes underground and reaches the surface almost instantaneously. Our geomechanical calculation shows that even for reservoirs as deep as 3 km, this stress brings about 1 cm of local surface elevation. This surface elevation is way beyond the detection precision of the common geophysical tools. We concluded that using normal tiltmeters is able to position the combustion front with about 5 m accuracy for 3 km deep reservoir. In-SAR data are also able to detect combustion front for shallower reservoirs. For a relatively shallow reservoir, we have calculated the combustion front position by using In-SAR and compared it with the local measurements.

We have also investigated the use of acoustic emission (AE) for tracking of combustion front. Since combustion front is a local stress phenomenon, is seems to be a perfect choice for using AE technique. For a 2 km deep reservoir, we detected AE events caused by combustion front received by geophones at surface. However, we concluded that the events are diffracted when arrived the major reservoir faults. The events locations were pretty much consistent with known reservoir faults. Nevertheless, it did not help us locating the combustion front. We suggest using downhole geophones for such purpose.

Modeling of Oil Recovery by In-situ Combustion in Deformable Fracture-Porous Medium Systems

Octavio Cazarez-Candia*, Pedro F. Aguilar-Gastelum, Elizabeth Cervantes Flores
Instituto Mexicano del Petróleo, Eje Central Lázaro Cárdenas 152, C.P. 07730, Del. Gustavo A. Madero, Ciudad de México, México.
* Corresponding author: ocazarez@imp.mx

Keywords: In-situ combustion, deformable matrix-fracture system, multi-phase and multi-component mathematical model, fracture width, combustion front.

In this work, a multi-phase and multi-component mathematical model, for oil recovery through the in-situ combustion process, is proposed for deformable fractured systems. It includes mass and energy balance equations for water, steam, oil, oxygen, inert gas (CO_x, N_2), and coke. Geomechanical equations were used to take into account the matrix and fracture deformations. The model was numerically resolved by using the finite element method, which is implemented in a PDE solver that is included in a CFD software. The mathematical model was used to simulate the in-situ combustion process in deformable fractured systems in in-situ combustion tubes. It was validated by comparing numerical results of temperature and oil recovery against experimental data from fractured systems. It was found that volumetric deformation of the matrix reduces the fracture width, consequently, the combustion front velocity is higher than the one for an undeformable system (Figure). Moreover, the generation and combustion of coke in the system increase, reaching a higher combustion front temperature. It was also found that, by increasing the volumetric flow of air injected in a deformable fractured system, the oil recovery time interval decreases, requiring a shorter injection period.

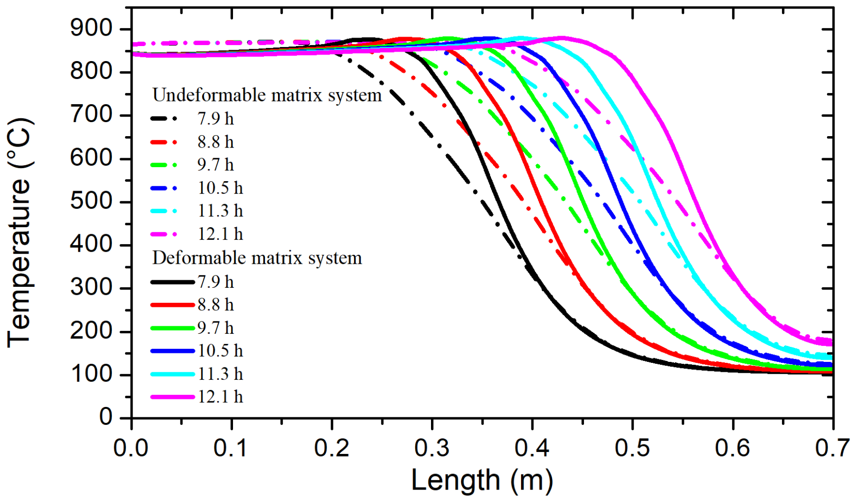


Figure 1. Effect of matrix deformation on the temperature profiles. The combustion front velocity is higher for a deformable system than for an undeformable system.

Crude oil oxidation characteristics using high-pressure differential scanning calorimeter

Xiaodong Tang [a, *], Wanfen Pu [a, b, *], Renbao Liu [a], Longwei Li [c], Yu Yang [d]
[a] State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, Sichuan 610500, China
[b] Tianfu Yongxing Laboratory, Chengdu 611130, China
[c] Nanhai Petroleum Research Institute of Zhanjiang Branch of China National Offshore Oil Corporation China Limited, Zhanjiang, Guangdong 524057, China
[d] Southern Sichuan Gas Mine of PetroChina Southwest Oil and Gas Field Company, Chengdu, Sichuan 642300, China
[*] Corresponding author: txdkali@163.com, puwanfen@126.com.

Keywords: Crude oil thermal characteristics; High-pressure differential scanning calorimetry; In-situ combustion; Kinetics

It is essential to study the factors effecting the combustion of crude oil, which directly determines the combustion efficiency of in-situ combustion. Therefore, this research performs series investigations about thermal behaviors and kinetics of light and heavy crude oil during combustion using high-pressure differential scanning calorimetry (HP-DSC) under four different pressures (3, 5, 8, 12 MPa) and four different oxygen concentration (5%, 10%, 15%, 20%) at a constant heating rate (10 °C/min). The results got from HP-DSC curves showed that the peak temperature decreased and the heat flow increased with the increase of pressure and oxygen concentration. The heat enthalpy of low temperature oxidation (LTO) was higher than that of high temperature oxidation (HTO) of light crude oil while that of heavy crude oil was opposite. It was observed that the heat release of LTO and HTO of both light and heavy oil increased linearly with the increasing of pressure and oxygen concentration and the heat enthalpy of higher oxygen concentration increased more obviously with the increase of pressure, meaning the heat release may be controlled by oxygen concentration for avoiding explosion caused by strong exothermic under higher pressure. it was suggested that the difference of heat enthalpy between LTO and HTO was more pronounced as the pressure increased than that of oxygen concentration.Besides,the kinetics of crude oil were analyzed using Borchardt & Daniels and Roger & Morris methods. It was found that the activation energy of light oil was lower than that of heavy oil, and the activation energy decreased as pressure and oxygen concentration increased. This study could obtain the some parameters related to the possible in-situ combustion filed applications, particularly the oxygen-reduced air injection of deep heavy oil reservoirs.

Development of methods for the intensification of the oxidation process of heavy oil with the application of catalyst compositions

Seyedsaeed Mehrabi-Kalajahi[a,b*], Fahimeh Hadavimoghaddam[c], Alexey Rozhenko[c], Mikhail A. Varfolomeev [a,b]

[a] Department of Physical Chemistry, Kazan Federal University, Kazan 420008, Russia

[b] Department of Petroleum Engineering, Kazan Federal University, Kazan 420008, Russia

[c] Institute of Unconventional Oil & Gas, Northeast Petroleum University, Heilongjiang, Daqing, 163318, China

[*]Corresponding author: ss.mehrabikalajahi@gmail.com, vma.ksu@gmail.com

Keywords: machine learning, in-situ combustion, heavy oil, oxidation, pyrolysis

Enhanced heavy oil recovery by in situ combustion (ISC) is still restricted as an attractive thermal method because of difficulties with ignition, inefficient combustion, and unstable combustion fronts. Hydrocarbon oxidation and pyrolysis reactions, which control fuel synthesis and heat evolution, are the main regulators of oil recovery during in situ combustion. In turn, crude oil pyrolysis can be used to correctly forecast fuel deposition utilizing thermogravimetry analysis (TGA). However, the theoretical models based on TGA runs might only be applicable to the available crude oil samples. This study content of two part. The first one dedicated of developing a robust methods for prediction residual mass during the process of oil pyrolysis based on algorithms such as XGBoost, ELM, MARS, CatBoost. The second part of the work was dedicated on developing ML models for prediction viscosity of dead oil based on experimental data. As we know the viscosity is a critical value in the process of Thermal EOR study. Lately, for those mentioned part of study, were developed two robust correlation algorithms, GMDH and GP, in order to develop the mathematical correlation for estimation dead oil viscosity and also for estimation of residual mass. In this study also was provided the sensitivity analysis which show that the temperature has the highest impact on target value in both of steps of research study. The results of black box algorithms and white box algorithm were shown and compared in this study. The results show that the robust developed correlation can simplicity provides very good estimates value.

Initiation of In-Situ Combustion of Heavy Oil by Ozonated Vegetable Oil

Saifullin E.R.*, Sadikov K.G., Halilov A.R., Varfolomeev M.A., Salihov R.Z.
Kazan Federal University, Russia
* Corresponding author: mr.emilsr@gmail.com

Keywords: in-situ combustion, initiator, vegetable oil, ozonide

Heavy oil reservoirs usually developed by steam injection methods in Russia. At some point injection of stream become uneconomical. There are several abandoned heavy oil reservoirs in Tatarstan republic. In-situ combustion technology can give "new life" for such reservoirs and prolonged their development.

This work present new method of initiation of in-situ combustion by ozonated vegetable oil injection. Ozonated vegetable oil degraded at approximately low temperatures and generate heat and oxygen radicals, which helps to accelerate combustion initiation process and its success rate. Laboratory study was performed using TGA, HP-DSC and ARC. It was shown that addition of ozonated vegetable oil shift oxidation reaction of oil to lower temperature range.

From THAI to Quasi-THAI. Clues to Heavy Oil In-Situ Upgrading from Analysis of Some In-Situ Combustion Field Projects: Focus on Reservoir Architecture

Alex Turta[a*], Ashok Singhal[b]
[a] A T EOR Consulting Inc, Canada
[b] Premier Reservoir Engineering Services, Canada
[*] Corresponding author: aturta@shaw.ca

Keywords: Heavy oil recovery; in-situ combustion; toe-to-heel air injection (THAI); quasi-THAI

In-situ Combustion (ISC) involves air injection into oil reservoirs to generate heat. The heavy oil thereby heated has reduced oil viscosity and hence, increased oil mobility. During ISC, peak temperature has been observed to rise to as high as 1,100 0C, depending on the nature of the heavy oil and reservoir conditions

The actual upgrading of the effluent oil depends on the point of fluid withdrawal. In conventional ISC operations, which are carried out with only vertical wells, the point of fluid withdrawal is the perforated interval of the production well, which are usually placed many 100s of metres away from the injection wells. That's why the thermally affected oil thus needs to travel long distances through the colder reservoir and in the process, it gets diluted to the extent that no significant upgrading is actually observed or reported.

The development of the novel ISC process, Toe-to-Heel Air Injection (THAI) brought a new perspective on ISC use for heavy oil recovery, namely iIt brought the perspective of using ISC both for oil recovery and in-situ oil upgrading. THAI involves a vertical air injector (s) and a horizontal producer (s) with its horizontal section located near the bottom of oil layer, having the toe close to the air injection well. Thus, in THAI, the fluid withdrawal points are much closer to the heated zone and involves much shorter distance of travel. Hence, the upgrading of the oil is preserved.

ROLE OF RESERVOIR ARCHITECTURE

In a uniform permeability reservoir, the injected air and the gaseous products of ISC reactions will tend to rise to the top of the pay interval, bypassing the oil residing near the base of the pay. In this case, in general, for medium and relatively thick formations oil in the lower part of reservoir remains unrecovered. However, based on the knowledge from THAI process it was found that for a variation of permeability on the vertical of the oil formation, there are two cases in which reservoir architecture favor the production of an in-situ upgraded oil even for conventional ISC carried out with just vertical wells.

A) Man-made, disc-fracture towards the bottom of oil formation (Quasi-THAI due to a Disc-Fracture)

A first step from going from THAI to Quasi-THAI is constituted by replacement of the horizontal section of horizontal producer with a disc-fracture located close to the bottom of oil formation. In reality, the single horizontal section of producer is replaced by an infinity of producers due to this fracture, while the control of operations may be a bit weaker. Therefore, it is natural to expect to produce upgraded oil in this particular case. This was fully demonstrated by the Quirock ISC pilot carried out by Gulf Research and Development in 1959-1960 (6-month test) in Kentucky, USA. In this pilot a precise horizontal fracturing was performed close to the bottom of pay, creating a possibility for inadvertently operating a Quasi-THAI process. Some essential information will be provided and discussed for this very convincing pilot having the best instrumentation ever recorded in an ISC pilot.

B) Stratification favoring the occurrence of oil upgrading ((Quasi-THAI due to a permeability architecture)

In pay intervals with permeability increasing upwards (coarsening upwards), the air/gas segregation effect will be further accentuated and lead to poor performance. In pay intervals with permeability increasing downwards (coarsening downwards), the above effect will be partially or totally compensated. In this last case, if the permeability increase in downward direction is pronounced or there is a thin layer of very high permeability at the bottom of a heavy oil formation, there are prospects of using ISC for in-situ upgrading, as well.

This conclusion from theoretical considerations was practically shown to be correct as four conventional old ISC projects in which no supplementary actions (to cause upgrading) have recorded a production of an in-situ upgraded oil for very long periods of time. It is suspected that a unique permeability distribution favoured a Quasi-THAI ISC. This occurred in 4 dry ISC projects located in USA, Venezuela and China. This includes the case of the pilot in China where ISC was conducted after steam flooding (preceded by CSS); some channellings towards the bottom of layer, formed during CSS and steamdrive could have been significant contributors to this upgrading. Some essential information will be provided and discussed for each of these four cases, totally unexplained at the time of their execution. The consequences related to the possibility of using ISC not only as a recovery method but also as an in-situ upgrading oil, in the future will be summarized. Also, some knowledge limitations and future aspects still to be fully clarified are discussed.

Tracking In-situ Combustion Front using Geophysical and Geomechanical Data

Mohammad Bazargan[a*], Anthony R. Kovscek[b]
[a] Currently at Chemical and Petroleum Engineering Department, Sharif University of Technology, Iran
[b] Energy Resources Engineering Department, Stanford University, US
[*] Corresponding author: mbazargan@sharif.edu

Keywords: In-Situ Combustion, Front Tracking, Geophysics, Acoustic Emission, In-SAR

World experience shows that the most common and effective methods for the development of extra-viscous oil are thermal, namely: steam treatment. However, the technology has a number of disadvantages that reduce their technical and economic efficiency. The main disadvantages of steam treatment are the high cost of steam generation and greenhouse gas emissions during its production, rapid formation watering, while the produced oil after cooling still has a high viscosity and density, which complicates its further preparation and transportation.

To solve these problems, a series of laboratory studies were carried out in the work and applied in a pilot area of a real field.

Laboratory studies were carried out on a unique scientific unit for physical modeling of the process of in-situ combustion and steam gravity drainage. The results of the physical modeling performed on the model of a carbonate reservoir with extra-viscous oil showed that in the presence of aquathermolysis catalyst, oil displacement increases by more than 1.5 times. It has also been shown that nanoparticles adsorbed on the rock can act during several cycles of steam injection. It is shown that the use of a catalyst, the active form of which is formed in situ, provides a decrease in the mass fraction of heavy components of oil, an increase in the fraction of saturated hydrocarbons, a decrease in the average molecular weight of oil, and a multiple decrease in oil viscosity.

Based on the results obtained, a formula was developed for calculating the volume of catalyst injection and a technology to produce extra-viscous oil in a carbonate reservoir by steam treatment with injection of a catalyst composition in a cyclic mode. Field testing demonstrated an increase in

super-viscous oil production of more than 2,000 t/sq compared to the previous steaming cycle without a catalyst. The results obtained confirm the prospects of using the developed technology to improve the efficiency of bituminous oil production.

HIGH PRESSURE AIR INJECTION (HPAI)

Thermo-oxidative Behavior, Kinetic Triplets, and Spontaneous Ignition Potential of Shale Oil during Air Injection

Shuai Zhao[a,b*], Wanfen Pu[a,b], Mikhail A. Varfolomeev[a,b], Chengdong Yuan[a,b], Chunyun Xu[a]
[a]State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, 610500, China
[b]Department of Petroleum Engineering, Kazan Federal University, Kazan, 420008, Russia
[*]Corresponding author: zs77816@163.com

Keywords: thermo-oxidative behavior; kinetic triplets; spontaneous ignition potential; shale oil; air injection

The oxidation reactions caused by air injection form the thermochemical/physical effects, which is expected to achieve energy enhancement by high temperatures, reservoir structure improvement, and multi-media flooding, thus becoming an important technology for shale oil production. However, the kinetic triplets and spontaneous ignition potential of shale oil during air injection was still not well-understood. In this work, differential scanning calorimetry (DSC) and high-pressure DSC (HP-DSC) were used to carry out dynamic oxidation tests of shale oil, with the intent of understanding the thermo-oxidative characteristics and kinetic triplets of shale oil under dynamic air flow. Then, accelerating rate calorimetry (ARC) was used to study the energy-enhancing and heat-enhancing characteristics of shale oil caused by oxidation reactions under different oxygen concentrations. The DSC and HP-DSC results that the thermal effect caused by LTO at 5MPa increased significantly compared with that under atmosphere pressure, which helped to the rapid transition from the LTO stage to the HTO stage. The most probable reaction mechanism function of the oil sample oxidation at 5 MPa was D_3 (three-dimensional diffusion, spherical symmetry), which proved that the microscopic reaction mechanism was mainly diffusion oxidation/combustion. The ARC results demonstrated that the shale oil used had excellent oxidation activity; while increasing the oxygen concentration from 16% to 26%, the oxidation induction period shortened and the burning intensity increased obviously. If the partial pressure of oxygen in the target block was not lower than that in the ARC tests conducted in this work, and the oxygen could fully contact with the shale oil, there would be a great potential for spontaneous ignition in this block during a high-pressure air injection process.

Alterations into Shale Structures Caused by Crude Oil Oxidation during Air Injection Process

Wanfen Pu[a,b], Chunyun Xu[a,*], Shuai Zhao[a,*]
[a]State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, People's Republic of China
[b]Department of Physical Chemistry, Kazan Federal University, Kremlevskaya Str. 18, 420008, Russia
[*]Corresponding author: 13893740173@163.com (C. Xu), zs77816@163.com (S. Zhao)

Keywords: Shale oil; Air injection; oxidation-thermal effect; Microstructure analysis

To investigate the pore structural improvement induced by shale oil oxidation during air injection process (AIP), the shale samples were subjected to oxidation reactions at different temperatures. Subsequently, low-temperature nitrogen adsorption (LTNA), acoustic emission (AE), and field emission scanning electron microscope-energy dispersive spectroscopy (FESEM-EDS) tests were conducted to comprehensively characterize the microstructure development within the shale. The LTNA results showed that the adsorption-desorption hysteresis loop closed when the oxidation temperature was increased to 300℃, implying closed micropore expanded after oxidation. In addition, the main mesoporous range of shale was changed from 3~4 nm to 10~20 nm while increasing temperature from 30 ℃ to 500 ℃. According to the adsorption-desorption curves and pore size distribution curves, it was believed that the pore size structure experienced the combination stage of closed pore communication and mesoporous expansion. The AE results showed that the damage factor calculated by the longitudinal wave was used to assess the extent of shale damage. The damage factor of shale was determined to be 0.43 under 500 ℃, indicating the shale reached the stage of micropore destruction. The FESEM images of original sample at micro confirmed the presence of various mineral, kerogen, and few natural fractures, along with inter-and-intra particle pores in the matrix. The intensified thermal damage of rock and the thermal oxidation of kerogen resulted in the expansion of microstructure with the elevated temperature. The findings of this study assisted in understanding the oxidation-thermal effect of shale oil on the development of pore structure.

CATALYTIC IN-SITU OIL UPGRADING

Definition of Reaction Pathways for Catalytic Aquathermolysis of Liaohe Heavy Crude Oil

Alexis Tirado[a], Guillermo Félix[a], Mikhail A. Varfolomeev[a], Chengdong Yuan[a], and Jorge Ancheyta[b] *
[a]Department of Petroleum Engineering, Kazan Federal University, Kazan 420008, Russia
[b]Instituto Mexicano del Petróleo, Eje Central Lázaro Cárdenas Norte 152, San Bartolo Atepehuacan, Mexico City, 07730, Mexico
* Corresponding author: jancheyt@imp.mx

Keywords: Kinetic modeling; aquathermolysis; sensitivity análisis

Kinetic models are valuable tools to understand reaction mechanisms as well as to predict the behavior of yields and selectivities of different reaction products and reactant species.

A five-lump scheme reported by Zhang et al. was used to analyze literature models and estimate the kinetic parameters based on literature experimental data obtained during the aquathermolysis of Liaohe extra-heavy crude oil using 30 wt.% of water, 5 wt.% of NiO catalyst, in a temperature range of 200-260 °C and reaction times of 12-72 h. The estimation of the kinetic coefficients was carried out through a methodology based on the selection of initial guess values, non-linear optimization, and evaluation of the resulting values through sensitivity analysis and statistical techniques.

The calculated profiles of SARA fractions and gas yields with the kinetic coefficients obtained show an accurate fit with experimental data. A maximum average absolute error of 3.22% concerning experimental data at 260 °C was obtained. Based on the results of reaction rate for each pathway, the following sequence is predominant at low temperatures (<240 °C): Re → Ar > Ar → Re > As → Sa > Re → As > As → Re. Nevertheless, the reaction rate to produce resins from asphaltenes has a sharp increase at high temperatures (>240 °C) and short time. As the reaction time advances, the reaction rates of asphaltenes and resins decrease since they approach chemical equilibrium.

Conditions reach the global minimum of the objective function, thus presenting a good fit concerning experimental data. Average absolute error values less than 4% were obtained at each operating temperature. The values of the kinetic parameters present coherence with respect to experimental data reported for the production of saturates and gases compounds. The product distribution indicates that the conversion of resins to produce aromatic compounds is the predominating reaction, while asphaltenes are mainly converted into saturates and gases.

Detailed SARA-Based Kinetic Model for Non-Catalytic Aquathermolysis of Heavy Crude Oil

Guillermo Félix [a], Alexis Tirado [a], Ameen Al-Muntaser [a], Michael Kwofie [a], Mikhail A. Varfolomeev [a], Chengdong Yuan [a], and Jorge Ancheyta[a, b *].
[a] Department of Petroleum Engineering, Kazan Federal University, Kazan 420008, Russia
[b] Instituto Mexicano del Petróleo, Eje Central Lázaro Cárdenas Norte 152, San Bartolo Atepehuacan, Mexico City, 07730, Mexico.
* Corresponding author: jancheyt@imp.mx

Keywords: Kinetic model; aquathermolysis; heavy oil.

To develop new technologies based on steam injection, it is necessary to identify the reactions that take place as well as to have appropriate kinetic models that predict the composition of the products generated during the aquathermolysis process. There are few kinetic models for the non-catalytic aquathermolysis reported in the literature. However, the composition of the liquid fractions still remains unknown during the aquathermolysis reactions. For this reason, a new kinetic model for the non-catalytic aquathermolysis of heavy crude oil is develop taking into consideration the SARA composition and gases as well as all possible reaction between them.

The heavy crude oil (Aschalcha) aquathermolysis reaction was carried out in a high pressure and temperature batch reactor with 300 mL of internal capacity. The water-to-oil ratio was kept constant throughout all experiments (70 g of crude oil and 30 g of deionized water). Nitrogen was used to remove impurities and generate a starting pressure of 2 bars, and different reaction times were utilized: 12 h, 24 h, 48 h, and 72 h. SARA fractions of heavy oil and upgraded oils were analyzed using a methodology based on the ASTM D 4124 technique.

The well-known general reaction of aquathermolysis includes the cleavage of C-S bond from heavy fractions to produce lighter hydrocarbons and gases, this main reaction can be separated in the conversion of organo-sulfur compounds in each SARA fraction to produce H_2S and other gases in water atmosphere. Based on this reaction scheme, the reaction rate equations can be derived and solved simultaneously in order to optimize the kinetic parameters values following certain constraints. The objective function based on the following average absolute error (AAE) is preferred.

The optimized kinetic parameters suggest that the reactions of aromatics and saturates to generate gases do not show to be sensitive to the temperature change. At both temperatures similar reactions are carried out: in series and some in parallel, nonetheless, at 300 °C the production of gases increases mainly due to asphaltenes conversion. The proposed kinetic model presents a good fit with experimental data since the AAE was less than 5%. The activation energies calculated in this work are in the range for those reported in the literature.

Catalytic aquathermolysis of a heavy oil extract in the presence of rock minerals

Gassan Khashan*, Sergey Sitnov
Kazan Federal University, Institute of geology and oil and gas technologies
* Corresponding author: khashan.ghassan@mail.ru

Keywords: Aquathermolysis; Catalyst; Hydrogen donor; Heavy oil

The influence of an oil-soluble iron-based catalyst together with a hydrogen donor on the process of converting an oil extract from the rock of the Ashalchinskoye field under conditions of catalytic aquathermolysis has been studied. Table 1 presents the results of a study of the influence of various factors (temperature, amount of catalyst and time) on the degree of conversion of heavy oil components according to the group chemical composition.

Table 1. Experimental results

№	Experiment conditions			Group components, % mass			
	Temperature, °C	Catalyst amount, % mass	Time, hrs	Saturated HC	Aromatic HC	Resins	Asphaltines
Initial oil extract sample							
1	-	-	-	39.2	30.1	25.4	5.4
Catalytic aquathermolysis products							
2	200	2	24	34.4	37.8	20.8	7.0
3	230	2	24	36.8	37.7	20.8	4.7
4	230	4	24	39.6	34.4	20.9	5.1
5	230	4	72	35.9	34.3	23.8	6.0
6	240	2	24	41.9	34.2	19.0	4.9
7	250	1	24	51.5	30.7	13.0	5.0
8	250	2	24	47.2	30.6	17.4	5.2
9	300	2	24	28.7	25	8.4	0.7

It can be seen from the table that the optimal temperature range for the efficient conversion of macromolecular compounds is 240–250°C, evident by the degradation of resins and asphaltenes as well as the generation of light hydrocarbons. At temperatures below optimal ones, oil conversion is less pronounced due to insufficient energy to activate the catalyst driven degradation process. At 300°C, an effective transformation of resin-asphalten compounds is observed, but the corresponding increase in light fractions does not occur, which is apparently associated with the formation of a large amount of coke. This assumption, in the future, will be investigated based on the results of thermogravimetric analysis of the extracted rock.

Ferrocene-based Ligand Catalysts for In-situ Hydrothermal Upgrading of Heavy Crude Oil: Synthesis and Application

Anastasia N. Mikhailova[a], Ameen A. Al-Muntaser[a, *], Muneer A. Suwaid[a], Rustem R. Zairov[b, c], Ibrahim T. Kadhim[a], Richard Djimasbe[a], Almaz Zinnatullin[d], Dmitrii A. Emelianov[a], Reyimkulyyeva S. Umarkulyevna[a], Mikhail A. Varfolomeev[a, *]

[a] Department of Petroleum Engineering, Kazan Federal Universit, Russia

[b]Aleksander Butlerov Institute of Chemistry, Kazan Federal University, Russia

[c] Arbuzov Institute of Organic and Physical Chemistry, FRC Kazan Scientific Center, RAS, Russia

[d] Department of Solid-State Physics, Kazan Federal University, Russia

* Corresponding author: vma.ksu@gmail.com, almuntaser.ameen@gmail.com

Keywords: heavy crude oil, in-situ catalytic upgrading, steam injection, Ferrocene-based ligands, enhanced oil recovery

Due to the growth in the volume of oil products production, the need to increase the depth of processing of heavy high-viscosity oils and the involvement of unconventional sources of hydrocarbons in oil production, together with thermal methods, the synthesis and development of catalysts become widespread, which make it possible to realize conversion of heavy oil directly in the reservoir.

In this work, the effect of synthesized Ferrocene-based ligand catalysts, including Mono-, Di- and Tri-Ferrocene, as additives for promoting the catalytic in-situ hydrothermal upgrading of Tatarstan (Russia) heavy crude oil was studied. In addition, the changes in composition of upgraded oil samples as well as the in-situ transformation and characteristics of used catalysts were evaluated in detail using a comprehensive analyzing techniques. All of the catalytic and non-catalytic hydrothermal upgrading experiments were carried out under the steam stimulation conditions at 300°C, 72 bar and 24 hours of reaction time. The results show that, introducing Ferrocene-based ligand catalysts to the upgrading system promotes the in-situ upgrading of heavy crude oil and improves the physical and chemical properties of upgraded oil samples. The maximum viscosity reduction was observed in presence Tri-Ferrocene and reached around 40% compared to non-catalytic hydrothermal upgrading. In addition, the upgrading performance also reflects as an increase of H/C ratio, reduction of sulfur content, increase of saturates and aromatics, and decrease of the content of resins and asphaltenes as well as a noticeable changes (increase) in the light fractions of C_{10}-C_{20} are observed for all upgraded oil samples. Mono-Ferrocene as an oil-soluble catalyst mainly transformed to the particles of Fe_3O_4 (Magnetite) and FeS, which can act as active forms of catalysts and accelerate the hydrothermal conversion of heavy crude oil and its heavy fractions including resins and asphaltenes. These transformations were confirmed using XRD, SEM-EDX and Mössbauer analyzing techniques. The good catalytic performance of used ferrocene-based ligand catalysts as well as their low cost and easy access makes them great potential catalysts for improving the efficiency of steam injection for heavy oil production and in-situ upgrading.

The work is carried out under the support of the Russian Science Foundation related to the Project № 21-73-30023 dated 17.03.2021.

Experimental Study the Effect of Reaction Temperature on the Donating Capacity of Water During Catalytic and Non-Catalytic Aquathermolysis Using Deuterium Tracing Technique

Muneer A. Suwaid*, Ameen A. Al-Muntaser*, Ali B. Alfarttoosi, Richard Djimasbe, Mikhail A. Varfolomeev*

Department of Petroleum Engineering, Kazan Federal University, Kremlevskaya str. 18, 420008 Kazan, Russian Federation

*Corresponding author: Mikhail A. Varfolomeev; vma.ksu@gmail.com; Muneer A. Suwaid; Suwaidmuneer@gmail.com; Ameen A. Al-Muntaser; almuntaser.ameen@gmail.com

Keywords: Deuterium tracing; Heavy water; Donating capacity; Isotope labelling; Catalytic aquathermolysis

Steam injection is one of the main in-situ viscosity reduction technologies for heavy and extra-heavy crude oil production, where aquathermolysis reactions (during catalytic and non-catalytic upgrading) take place and play a major role in the improvement of flow properties of the heavy oil.

In this work, the main goal is to try to figure out the role of water as a hydrogen source in catalytic and non-catalytic aquathermolysis by using isotope tracing techniques and study the effect of reaction temperature on the donating capacity of water. For this purpose, heavy water (deuterium oxide, D_2O) was used to replace the ordinary water (H_2O) for catalytic and non-catalytic aquathermolysis processes of heavy oil with high sulfur content in autoclave at different temperature (200, 250 and 300 °C) for 24h. The donating and upgrading performance of D_2O were deeply investigated by analyzing the upgraded (deuterated) oil using different tracing techniques (FTIR, isotope and elemental analysis), evolved gases by GC, and change in physical-chemical properties of upgraded (deuterated) oils by viscosity measurement, asphaltene and maltene fraction and elemental analysis, etc. The results proved the chemical role of water as a green and environmental hydrogen-donor solvent during aquathermolysis process, verified by considerable deuterium substitution (deuteration) obtained from isotope analysis in upgraded oil. The FTIR tracing results show deuterium exchanges (deuteration) in both the aliphatic and aromatic parts of the upgraded oil. The FTIR fingerprint reflected of deuterium isotopes connected to single bonds (C-D) linked to aliphatic and double-bond (C=D) linked to aromatic compounds. Simultaneously, introducing Ni-stearate as an oil-soluble catalyst promoted the donating capacity of water, thus significantly improving the upgrading performance. The important finding about the role of water in catalytic and non-catalytic aquathermolysis not only enriches the theoretical basis in this area, but also provides a strong support for the use of catalysts in aquathermolysis for improving in-situ heavy oil upgrading performance. Generally, by increasing the temperature reactions from 200 to 300°C the donating capacity of water increased according to the results of isotope analysis.

This work has been supported by the Kazan Federal University Strategic Academic Leadership Program (PRIORITY-2030).

Application of catalytic aquathermolysis technology to extra-viscous oil deposits: from laboratory screening to field tests

Mikhail A. Varfolomeev [a*], Ilgiz F. Minkhanov [a], Irek I. Mukhamatdinov [a], Alexey V. Vakhin [a], Alexander V. Bolotov [a], Kirill A. Dubrovin [b], Yaroslav O. Simakov [c], Alexey V. Soloviev [b]
[a] Kazan Federal University, Russia
[b] JSC «Zarubezhneft», Russia
[c] JSC «VNIIneft », Russia
* Corresponding author: vma.ksu@gmail.com

Keywords: catalytic upgrading; extra-viscous oil; physical modeling; catalytic aquathermolysis

World experience shows that the most common and effective methods for the development of extra-viscous oil are thermal, namely: steam treatment. However, the technology has a number of disadvantages that reduce their technical and economic efficiency. The main disadvantages of steam treatment are the high cost of steam generation and greenhouse gas emissions during its production, rapid formation watering, while the produced oil after cooling still has a high viscosity and density, which complicates its further preparation and transportation.

To solve these problems, a series of laboratory studies were carried out in the work and applied in a pilot area of a real field.

Laboratory studies were carried out on a unique scientific unit for physical modeling of the process of in-situ combustion and steam gravity drainage. The results of the physical modeling performed on the model of a carbonate reservoir with extra-viscous oil showed that in the presence of aquathermolysis catalyst, oil displacement increases by more than 1.5 times. It has also been shown that nanoparticles adsorbed on the rock can act during several cycles of steam injection. It is shown that the use of a catalyst, the active form of which is formed in situ, provides a decrease in the mass fraction of heavy components of oil, an increase in the fraction of saturated hydrocarbons, a decrease in the average molecular weight of oil, and a multiple decrease in oil viscosity.

Based on the results obtained, a formula was developed for calculating the volume of catalyst injection and a technology to produce extra-viscous oil in a carbonate reservoir by steam treatment with injection of a catalyst composition in a cyclic mode. Field testing demonstrated an increase in

super-viscous oil production of more than 2,000 t/sq compared to the previous steaming cycle without a catalyst. The results obtained confirm the prospects of using the developed technology to improve the efficiency of bituminous oil production.

Nanotechnology and Heavy Oil Oxidation: The Impact of Particles' Size on In-Situ Combustion Kinetics and Thermodynamics

Mohammed Amine Khelkhal[a*], Alexey A. Eskin[a], Semen E. Lapuk[b], Alexey E. Buzurov[b], Mikhail A.Varfolomeev[a,b*]

[a]Department of Petroleum Engineering, Kazan Federal University, 18 Kremlyovskaya str., 420008 Kazan, Russia

[b]Department of Physical Chemistry, Kazan Federal University, 18 Kremlyovskaya str., 420008 Kazan, Russia

[*]Corresponding author: amine.khelkhal@gmail.com, vma.ksu@gmail.com

Keywords: nanoparticles; heavy oil oxidation; in-situ combustion; catalysis; thermal analysis

The world is witnessing nowadays a serious geopolitical crisis due to the high demand of energy and the lack of resources. Heavy oil resources are of great interest in term of sustaining the market demand. However, their exploitation still represents the major challenge due to the high viscosity and low mobility of these oils in the reservoir. Enhanced oil recovery methods are promising technologies which allow the production of heavy oil with significant efficiency. Much of the literature points toward the high efficiency of in-situ combustion in enhancing heavy oil recovery because of its economic and time effectiveness. Yet, this technique suffers from the early breakthrough of the created combustion front within the reservoir. This work sheds light on stabilizing the combustion front via manganese based nanoparticles. We used physic-chemical analysis coupled with thermal analysis and isoconversional and model-based methods to find out the kinetic parameters and thermodynamic functions related to the process of heavy oil oxidation in the presence and absence of the obtained catalysts. The efficiency of the synthesized catalysts was found mainly dependent on the nanoparticles size and aggregation state. The synthesized nanoparticles have decreased the activation energy of heavy oil high-temperature oxidation region from 162 kJ.mol-1 to 131 kJ.mol-1. Moreover, the activation energy of the process of heavy oil oxidation has decreased significantly in the presence of manganese oxide nanoparticles supported by nanoparticles of silicon oxide. The evidence from this study suggests that the choice of the metal size and surface properties is crucial for its application in the process of in-situ combustion. Our study found out that the most efficient way to avoid nanoparticles aggregation during the process of heavy oil in-situ combustion is their fixation on the surface of silicon dioxide nanoparticles.

MODELING AND SIMULATION OF THERMAL EOR

Numerical Simulation of the Implementation of Hydrogen Peroxide in Oil Ignition for In-situ Combustion EOR Process

Allan A. Rojas*, Mikhail A. Varfolomeev, Vladislav A. Sudakov
Department of Petroleum Engineering, Geology and Petroleum Institute, Kazan Federal University, Russia
*Corresponding author: allanrojas5@gmail.com

Keywords: Hydrogen peroxide, thermal EOR, oil ignition, in-situ combustion

The in-situ combustion is one of the most promising thermal EOR methods available for the last century. However, some challenges are encountered during its implementation, such as during the oil ignition stage. The implementation of the oil ignition method, whether spontaneous or aided is dependent on the initial reservoir temperature. The spontaneous ignition may or not require the addition of more reactive oils as linseed oil. Meanwhile aided ignition may require the use of heaters, burners, chemicals, etc. Moreover, the worldwide experience in combustion pilots shows that the ignition stage may take from a few days to up to a few months, which increases the OPEX of projects.

The decomposition of hydrogen peroxide releases water/steam, O_2 and heat. The great thermal potential of the decomposition reaction of hydrogen peroxide can lead to substantial increments in the reservoir temperature above the ignition temperature of certain candidate oils for in-situ combustion. The decomposition products make of hydrogen peroxide a unique igniter as they own the essential components for a proper oil ignition process.

To study the implementation of hydrogen peroxide as an oil igniter for in-situ combustion process, two kinetic models were implemented. The first kinetic model corresponds to the decomposition reaction of Hydrogen peroxide obtained from the widely reported in literature. The second kinetic model corresponds to an oil combustion model previously published by the author where the temperature peaks, combustion front speed, cumulative oil production and residual oil saturation of a combustion test were closely matched to the experimental data. The numerical experiments were run with CMG STARS. During the simulations, hydrogen peroxide was injected and observed the peak temperatures caused at each injection regime. After few hours, air injection was initiated. The results showed that a quick oil ignition process and a successful HTO mode can be achieved.

This paper discusses the effects of hydrogen peroxide on increasing the reservoir temperature, the low technical limits of the injection rate and concentration for a successful ignition process and the timing for its achievement. This method is considered to be competitive to current available methods for oil ignition.

Oil Upgrading and History Matching of the Ashalchinskoye Heavy Oil Field Using a Compositional SARA-based Non-catalytic Aquathermolysis Kinetic Model

Allan A. Rojas*[a], Mikhail A. Varfolomeev[a], Jorge Ancheyta[a,b], Chengdong Yuan[a], Vladislav A. Sudakov[a]
[a]Department of Petroleum Engineering, Geology and Petroleum Institute, Kazan Federal University, Russia
[b]Mexican Institute of Petroleum, Mexico
[*]Corresponding author: allanrojas5@gmail.com

Keywords: oil upgrading, thermal EOR, Aquathermolysis kinetics, CSS

With the exception of some Canadian fields and authors, conventionally the numerical simulation of oil recovery with steam-based methods is carried-on with a single hydrocarbon component with an oil viscosity curve with temperature dependence and special set of relative permeabilities. These models neglect the effect of the in-situ oil upgrading and gas evolution which ultimately impact on the physical and flow conditions of the reservoir. The meaningfulness of this, is that advanced tasks of reservoir optimization forecasts which is one of the key advantages of reservoir simulation, may lead to unreliable predictions of the oil recovery rates.

In this work, for the first time it is presented a dedicated and detailed kinetic model with ten chemical reactions for numerical simulation of non-catalytic aquathermolysis reactions and in-situ oil upgrading of the Ashalchinskoye oil field of the Tatarstan Republic (Russia). The PVT model includes four oil pseudocomponents (SARA) and five gas components (CH_4, CO_2, H_2S, H_2 and a heavy molecular weight gas). The partition coefficients for the aquathermolysis product gases are included for the oil and water phases to account for the gas dissolution effects. The kinetic model is validated by history matching autoclave runs at different experimental temperatures. Furthermore, the kinetic model is integrated into a field scale model and history matches the oil production with a CSS well. The numerical simulations were run with CMG STARS.

By history, during the end of the second and third production period, the oil production of the well significantly dropped to rates lower than 2.6m^3/day and 0.5m^3/day, respectively. The results of numerical simulation with the kinetic model of in-situ oil upgrading show close correspondence of the increment of the heavy oil fractions in the wellbore vicinity and the historical reduction in oil production in both cycles. This proposes that the kinetic models can provide useful means to the better understanding of the underground processes occurring specially during advanced cycles of oil production using CSS that ultimately allows a more effective decision making. Additionally, the model is able to predict the production of green house and acid gases as well as environmentally clean fuel as H_2.

Numerical Simulation of the Complex Technology for the Bazhenov Formation Development

Petr Pyatibratov, Daniel Skorov*
National University of Oil and Gas «Gubkin University»
* Corresponding author: danilskorov@gmail.com

Keywords: Numerical simulation, unconventional resources, supercritical CO_2 injection.

The Bazhenov formation is a native rock which contains different types of hydrocarbons: mobile oil, adsorbed oil and kerogen. There are several technologies that allow converting solid hydrocarbons into liquid or gaseous and producing them. According to several scientific papers, these include cyclic treatment with supercritical or subcritical water. Heat injected into the Bazhenov formation with water transforms kerogen to “synthetic” hydrocarbons in-situ. After a while, synthetic and original oil is produced. Based on the numerical simulations, authors of these papers suggest that supercritical (or subcritical) water injection should lead to the highest volume of oil recovery.

In this work, we compared two cyclic technologies that differ in the injection agent (subcritical water and a mixture of subcritical water and supercritical carbon dioxide) using numerical simulation. The main difference of the model used is that it takes into account a larger number of in-situ processes, such as thermal- and component-dependent desorption of high-weight hydrocarbons, dissolution of CO_2 in the aqueous phase, geochemistry (ion exchange and calcite dissolution reactions), clay swelling, release of clay particles and their settling. All above mentioned processes were mathematically described and matched with laboratory experiments reported in the scientific papers.

The conducted numerical simulations allow us to conclude that the injection of pure subcritical water will lead to the release of clay particles and their settling in the near-wellbore zone. Gradual clogging of the pore and microfracture structure with clay particles will lead to a decrease in well productivity. In contrast to this, the injection of a mixture of subcritical water and supercritical carbon dioxide mixture will reduce the amount of clay particles released, since the near-wellbore region will be characterized by low pH values. The fewer particles will be released, the less damage will be done to the near-wellbore zone. The conclusions drawn are suggested to be relevant for similar shale fields.

Numerical Evaluation of the Effect of Heavy Crude Oil Reactivity on the Recovery Factor in Steam Injection Processes with Catalysts

Deivit Hernández*, Adan Y León*, Paola A Leon*
[a] Enhanced Recovery Research group, Industrial University of Santander, Colombia
[b] Enhanced Recovery Research group, Industrial University of Santander, Colombia
* Corresponding author: deivit9702@hotmail.com, adanleon@uis.edu.co, Paleonna@outlook.com

Keywords: Numerical simulation; catalytic Aquathermolysis; pseudocomponents; heavy crude oil; recovery factor

This research presents an experimental and numerical simulation study on the effect of the composition of three Colombian heavy crudes on their in situ upgrading and the recovery factor in steam injection processes with catalysts. For this purpose, direct measurements of density, viscosity and simulated distillation were carried out by means of experimental physicochemical characterization techniques for each of the three crudes, before and after the catalytic aquathermolysis reactions. The development of the numerical simulation model comprises the construction of a conceptual simulation model using STARS software for a Colombian field where steam injection works are currently being carried out. On the other hand, the fluid models were made in the Winprop tool and consisted of the separation of each crude oil in five pseudocomponents to represent the initial crude oil and the generation of reactions between them through kinetic parameters to represent the addition of the catalyst to the process. The experimental results showed that the crudes that manage to increase their mole fraction in light pseudocomponents such as distillates and naphtha due to the addition of the catalyst to the conventional steam injection process, have a permanent change in the physicochemical properties measured, since they increase the API gravity by up to 2.9 °API compared to the base crude, reducing in turn the viscosity by up to 53% and managing to produce a higher percentage of liquid. The simulation results for a live crude oil show that for a crude oil with an API gravity of 12.3 and with a distillate mole fraction close to 0.13 and 0.52 residue, the use of catalysts in continuous steam injection processes could generate an increase in the recovery factor of up to 8.9%, compared to the conventional technique. On the contrary, in a crude oil with an API gravity of 7.9 and a residue mole fraction of 0.57, the influence of the catalyst is negligible. This behavior may be associated with the fact that the breakdown of heavier components requires higher temperatures and higher hydrogen production to inhibit the polymerization of the new organic molecules. The performance of the process is a function of the operating conditions, especially temperature, residence and/or contact times and the reactivity of the crude oil. For the numerical simulation of in situ crude oil upgrading, it is of vital importance the correct development and adjustment of a compositional fluid model through the generation of pseudocomponents in the Winprop tool. In this way, it is possible to represent the properties of the initial crude, the properties of the upgraded crude and the effect on the recovery of the hybrid technology. The representation of the upgrading through the occurrence of reactions between the pseudocomponents under the evaluated conditions allows breaking the barriers of commercial simulators.

Physical and mathematical modeling results of the thermochemical treatment technology

Sergey Durkin, Konstantin Pchela, Alexander Osokin
SamaraNIPIoil Ltd, Russia

Keywords: thermochemical treatment, heavy oil, laboratory research, hydrodynamic modeling.

The purpose of the project is the development a composition for the thermochemical treatment technology in order to intensify the production of high-viscosity oil.

The thermochemical composition is an aqueous solution of salts based on ammonium nitrate, sodium nitrite, potassium/calcium nitrite and an aqueous solution of the reaction initiator ("Initiator Solution"), which is an aqueous solution of acetic acid, or an aqueous solution of formalin, or a mixture of formalin and hydrogen peroxide.

Having studied the ability of potassium nitrite to dissolve in a mixture consisting of ammonium nitrate and sodium nitrite, it was found that this makes it possible to increase the concentration of nitrites in the composition of a binary mixture during a thermochemical reaction, due to which a stronger release of gas and heat is observed. When mixing the salt solution and the initiator solution in the bottomhole formation zone, an exothermic reaction occurs, during which a local increase in temperature and pressure occurs, which can favorably affect the reduction of the skin factor. In the process of conducting laboratory studies, various schemes for the supply of composition and the reaction activator were considered and studied.

Calculations were performed using a non-isothermal compositional model to study the kinetics of chemical reactions and find the activation energy required for further calculations on address models of deposits to justify the program of pilot tests.

Efficiency prediction of thermal recovery method on high-viscosity oil field

Yuri Alekseevich Kotenev, Shamil Khanifovich Sultanov, Nikita Vladislavovich Shabrin*, Bibigul Zhaparovna Turkpenbayeva

FSBEI HE "Ufa State Petroleum Technological University"

* Corresponding author: nikita.shabrin@yandex.ru

Keywords: high-viscosity oil field, thermal recovery method, Buckley-Leverett function, water-oil mixture

Most effective method of high-viscosity oil field development is thermal recovery method. There are two problems of using this method. First is unstable displacement front that connected with different mobility of water-oil mixture before and after thermal zone. This is the reason for the water coning formation. Second problem is low efficiency of thermal energy using.

There are five productive formations combined into two production facility at the researching field. All of object have bottom water, viscosity difference between formations variating about third times, also second facility have increased permeability compared to first.

Efficiency prediction of heated water injection based on Buckley-Leverett functions. Phase permeability was modeled as standart potential function.

Calculations of cyclic thermal effects were carried out in two versions: using conventional tubing in injection wells and equipped with heat-insulated pipes to research efficiency of thermal energy using. Same calculations were carried out for thermal polymeric injection to research influence of water coning. The results were compared with the base case.

To sum it up thermal recovery method show higher oil recovery factor compared with base case. As the result, increasing is about twice (table 1).

Table 1 - Comparing oil recovery factor

Production facility	Method	Resulting oil recovery factor	Increase (compare with base)
1	Base	0.13	-
	Thermal recovery, base tubing	0.25	0.12
	Thermal recovery, thermally-insulated tubing	0.30	0.17
	Thermal polymeric injection, base tubing	0.30	0.17
	Thermal polymeric injection., thermally-insulated tubing	0.32	0.19
2	Base	0.10	-
	Thermal recovery, base tubing	0.16	0.06
	Thermal recovery, thermally-insulated tubing	0.19	0.09
	Thermal polymeric injection, base tubing	0.19	0.09
	Thermal polymeric injection., thermally-insulated tubing	0.22	0.12

This work was supported by the Ministry of Science and Higher Education of the Russian Federation under agreement No. 075-15-2022-297 within the framework of the development program for a world-class Research Center.

Dynamic Simulation of the Filtration Process Based on the Streamline Technology, Monitoring and Prediction of EOR and Stimulation Methods

Mahammad A. Jamalbayov[a*], Ilyas R. Hasanov[a], Nazim A. Valiyev[a], Mehmet O. Dogan[b], Tayfun M. Jamalbayli[b]
[a]SOCAR "OilGasScientificResearchProject" Institute, Baku, Azerbaijan
[b]METU, Ankara, Turkiye
[*] Corresponding author: mehemmed.camalbeyov@socar.az

Keywords: dynamic modeling, simulation, monitoring, formation stimulation, streamline

The purpose of the work is to model the filtration processes in gas condensate and oil (including volatile oil) reservoirs operated by production and injection wells of an arbitrary number on any coordinates, on the basis of which the creation of a computer simulator for visualization and predicting the process and evaluating the effectiveness of EOR and stimulation methods.

The solution was obtained on the basis of streamline technology, taking into account reservoir rock deformations, PVT properties of reservoir fluids, multi-phase flow, mass transfer between phases, etc. For this purpose, have been used the previous results of the authors in the field of the two-dimension filtration modeling of complex hydrocarbon systems, such as gas condensate mixture and volatile oils in deformable reservoirs; material balance equations are applied for the cases under consideration, on the basis of which equations are obtained for determining reservoir pressure and saturation of pores with liquid phase at any point of the reservoir. It is also used the algorithm of the authors to calculate influx at a given bottom hole pressure or drawdown. The solution to the problem was obtained thanks to the idea of the time discretization.

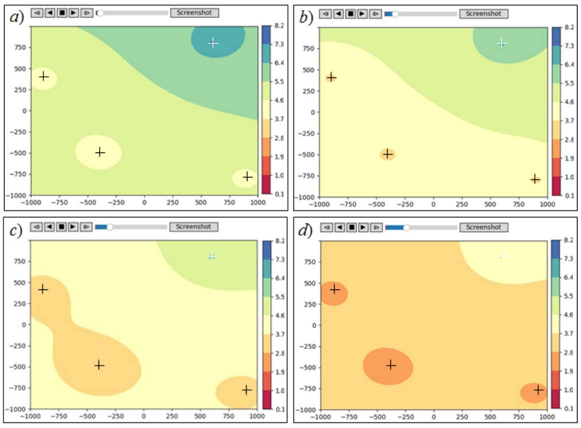


Figure 1. Demonstration of visualization of the gas condensate mixture filtration process between four wells at various stages *a, b, c*, and *d*.

A computer simulator was created on the basis of the obtained mathematical model. It was tested on examples of gas condensate and volatile oil reservoirs. The results confirmed the adequacy of the obtained mathematical model, on the basis of which the simulator was developed. Figure 1 shows the filtration process (pressure distribution) between the wells (the upper well is an injection well).

Studies have demonstrated the effectiveness of the obtained streamline-based solution. It has a number of advantages over Finite-Difference Simulation: It requires fewer data and fewer computational resources, hence it is easy and fast to implement; it is faster and works in real-time. The proposed streamline-based solution can be used to predict the effectiveness of reservoir stimulation methods including thermal stimulation. The results once again showed the wide possibilities of streamline technology.

Oxidation model, thermodynamic phase behavior and heat mass transfer of heavy oil during in-situ combustion

Liangliang Wang [a], Tengfei Wang [b,*], Wei Song [a], Yi Chen [a], Jiexiang Wang [a], Chengdong Yuan [c]
[a]School of Petroleum Engineering in China University of Petroleum (East China), Qingdao 266580, China
[b]College of Chemistry & Environmental Engineering, Yangtze University, Jingzhou, 434000, China
[c]Department of Petroleum Engineering, Institute of Geology and Petroleum Technologies, Kazan Federal University, Kazan, 420008, Russia
[*]Corresponding author: Tengfei Wang, Email: wangtengfeiforever@126.com

Keywords: In situ combustion; Heavy oil; Oxidation reaction; Phase behavior; Heat mass transfer

In situ combustion (ISC) has been used in heavy oil reservoirs for more than 90 years with many economically successful projects, and has become one of the popular thermal recovery techniques with great application potential. The concise review of the relevant works shows that most of the failures in the field test came from the application of a good ISC process to the wrong reservoirs or the poorest prospects, so it is regarded as a high-risk process by many. Accurate numerical simulation is of great significance for predicting the field performance of ISC technology and setting its key parameters. During the construction of numerical modeling, the following essential difficulties are faced: proper oxidation reaction models, accurate determination of phase behavior, and heat mass transfer. This work is dedicated to the construction and validation of oxidation reaction numerical models through TG, DSC, PDSC, TG-FTIR, GC-MS, etc. tests to provide proper ISC kinetic models for heavy oil reservoirs. Then, Understanding the phase transition behavior of heavy oil-air in the ISC process is beneficial to improve the development effect by controlling the phase composition of multiphase and multicomponent fluids. Finally, the heat mass transfer process of heavy oil oxidation reaction was studied based on the self-developed double-stirred high-temperature and high-pressure reactor, and the mathematical model of mass transfer process including chemical reaction was established to reveal the coupling mechanism of oxidation reaction-mass transfer in porous media heavy oil-air system. Based on practical engineering problems, the work could lay a theoretical foundation for the successful implementation of heavy oil ISC technology and provide a scientific basis for development policy research.

Development of an Automated Control System for Transferring Oil Wells from Continuous to Intermittent Mode

İbragim A Habibov*, Almaz M Mehdiyeva, Parvana S Jafarova
Azerbaijan State Oil and İndustry University, Baku, Azerbaijan

Keywords: mechanized methods; deep pumping; water factor; oil wells; periodically transfer; control system.

The oil fields that located on the Absheron peninsula are experiencing the last stage of exploitation. Their level of irrigation is 95-98% at the present time. Despite the relatively low level of this indicator in the deposits of Azerbaijan that located in the Caspian Sea, the process is intensifying. Usually, mechanized methods of oil extraction are used in the fields, including the deep pumping units with a barbell.

At the same time, it should be noted that the main cause of pollution in the areas of the oil-gas production departments falls on the well stock, which is operated with the numerous depth pumps. This is due to the large amount of water factor in the composition of the extracted product, its mineralization, oil and other impurities.

In order to eliminate the sources of pollution of the oil field or to reduce these sources, it is urgent to periodically transfer marginal deep pumping wells to operational mode and to develop an automated control system to control this process.

The results of the work done to solve this process are reflected in the article.

ELECTRICAL AND ELECTROMAGNETIC HEATING EOR

Study of Thermal Upgrading of Crude Oils Mediated by Microwaves in Presence of $GO@Fe_3O_4$ Nanocomposite

Nelson Gutierrez[a], Elcy Mariana Pérez[a], Nicolás Santos[b], Enrique Mejía-Ospino [a,b*]
[a]Laboratorio de Espectroscopia Atómica y Molecular (LEAM), Universidad Industrial de Santander, Piedecuesta, Santander, Colombia
[b]Grupo de Investigación en Tomografía Computarizada, Universidad Industrial de Santander, Bucaramanga, Colombia
[*]Corresponding author: emejia@uis.edu.co

Keywords: Thermal upgrading; EOR; THEOR; Graphene Oxide; Magnetite

Currently, crude oil extraction processes have become a problem of political, social and environmental interest; the demand for energy resources is increasing and it is a challenge for the petroleum industry to increase the recovery factor and to increase the reserves due to the fact that new deposits of great magnitude have not been found in recent years. That is why the crude oil industry has focused its efforts on enhanced oil recovery. In heavy oil reservoirs, the most commonly used enhanced oil recovery (EOR) methods are thermal oil recovery (TEOR) methods. Thermal methods have enabled the production of billions of barrels of crude oil. The first TEOR procedures date back to 1865, but the first significant industrial thermal method project was deployed in Woodson, Texas in 1931. Today there are a variety of thermal methods for the recovery of crude oil, one of the most innovative is the one that uses electromagnetic radiation in the microwave and/or radiofrequency range for reservoir heating. Today there are a variety of thermal methods for the recovery of crude oil, one of the most innovative is the one that uses electromagnetic radiation in the microwave and/or radiofrequency range for reservoir heating. In this work, we have synthesized and prepared nanofluids of graphene oxide (GO) and magnetite nanocomposites ($GO@Fe_3O_4$), and used them as a resonant system to microwave radiation at 2.4 GHz for the purpose of controlled heating of a heavy crude oil. We have observed that depending on the power of the microwave radiation, the crude oil can undergo physical or chemical modifications. The physical modifications show a noticeable decrease in the viscosity of the crude oil. While the chemical changes are responsible for the production of lighter species improving notably the viscosity and the quality of the crude oil.

Accounting for the Long-Term Influence of the Electromagnetic Heating of the Oil Reservoir on the Well Yield

Ismail Elshan ogly Dzhariev*, Egor Arkadievich Petrov, Sergey Mikhailovich Sysoev
Department of Automated Information Processing and Management Systems of the Polytechnic Institute
*Corresponding author: dzhariev2_ie@edu.surgu.ru

Keywords: well flow rate; high-viscosity oil; microwave electromagnetic radiation; accounting for the long-term influence.

The considered method of influencing the reservoir in this paper is one of the promising methods of thermal influence. Volumetric heat generation and deep penetration of electromagnetic radiation provides a high heating rate On models close to real conditions, the main task is to determine the optimal modes of impact on the reservoir.

A mathematical model is proposed, consisting of a piezo-conductivity equation, which includes the rate of oil filtration in the reservoir according to Darcy's law and the heat conduction equation taking into account phase transitions, an equation for an electromagnetic field with volumetric heat release in the medium. The influence of electromagnetic radiation is manifested only in the creation of volumetric heat sources, the power and distribution of which are determined by the power of the radiation source, the frequency of electromagnetic waves, the directional pattern of the antenna and the electro-physical parameters of the medium.

A computer study of the heating model of high-viscosity oil in the reservoir using microwave electromagnetic radiation was carried out. Spatio-temporal distributions of electromagnetic field intensity, temperature, pressure, oil viscosity and filtration rate are obtained. The additional well flow rate was calculated as a result of electromagnetic heating of the oil reservoir, taking into account the long-term effect of heating (Figure 1). The energy balance of the EROI electromagnetic influence on the oil reservoir is estimated, taking into account the long-term effect of heating.

In the problem under consideration, a new method is proposed to increase the flow rate of a well for reservoirs with high-viscosity oil by heating with electromagnetic radiation. The technology is effective if the energy profitability (EROI) is equal to or greater than ten. The results obtained for EROI 13.2 and 23.2 satisfy the specified criterion. However, the calculation of the second option shows that taking into account the long-term effect of electromagnetic heating of the oil reservoir on the well flow rate allows us to more correctly take into account the efficiency of the technology, and the resulting value of the energy balance assessment coefficient in the first option is more than 1.7 times lower than in the second option. Thus, electromagnetic influence on the bottom-hole zone of the formation is an effective technology from a practical point of view.

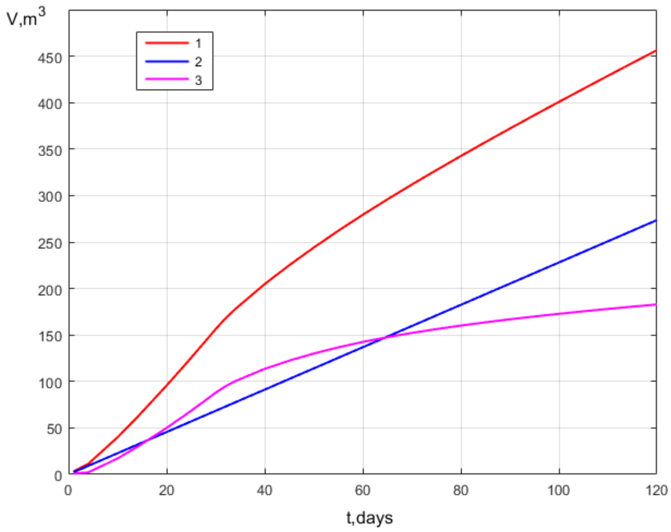


Figure 1. The dependence of the volume of additionally produced oil on time for electromagnetic heating of the reservoir by microwave radiation (parameters of the electromagnetic radiation source: W=10 kW, f=1 GHz): 1 – the volume V_1 of oil produced when the reservoir is heated by an electromagnetic radiation source for 30 days and the subsequent extraction of oil from the reservoir into the well for 90 days; 2 – the volume V_2 of oil produced from a "cold" well; 3 – volume of additionally produced oil ΔV due to the heating of the reservoir

Study the Microwave Heating Methods for Oil Recovery

Sudaba H. Novruzova, Yelena Y. Shmoncheva*, Gullu V. Jabbarova
Azerbaijan State Oil and Industry University (ASOIU)
* Corresponding author: yelena.shmoncheva@asoiu.edu.az

Keywords: microwave energy; heating; oil; rock; enhanced oil recovery.

At present, there are many deposits of heavy oil in the world with thin productive strata. As practice shows, often conventional methods of steam injection are not cost-effective for such reservoirs. This results in significant heat loss. This problem can be minimized by controlled microwave heating of the tank. In Azerbaijan, there are residual deposits of high-viscosity oils in the Balakhani-Sabunchi-Ramany field (viscosity 75-110 mp·s).

The purpose of this study is to experimentally study the effect of microwave heating on the viscosity of oil and the formation of cracks in rocks.

The study showed the benefits of microwave heating:

- Volumetric environmentally friendly heating;
- selective heating;
- increase in the speed of processes during microwave heating;
- high coefficient of conversion of microwave energy into thermal energy.

The report presents the results of laboratory studies on microwave heating of rock and oil samples.

In microwave heating, microwaves act on water molecules, and the water molecule is heated, and then this heat is transferred to the formation. Also, during microwave heating of dielectrics in a multicomponent mixture, those components that have high values of dielectric losses will be heated faster. Therefore, it is possible to develop and use hybrid schemes for heating dielectrics.

The study analyzed rock samples before and after microwave heating. The analysis was carried out using scanning electron microscopy to quantify surface microcracks and micro-CT to determine the volume of microcracks.

Summing up the results of the study, the following conclusions can be drawn:

- processing of samples by microwave heating has a large number of advantages compared to traditional heating;
- a decrease in the viscosity of oil samples corresponds to the effect of microwave heating for 45-50 s at its power of 2 kW. A further increase in the duration of heating has practically no effect on the decrease in the viscosity of the samples.
- for each sample, the values of the efficiency of microwave heating were determined;
- the intensity of microcracks in rock samples increases with an increase in the power level from 2 kW to 3 kW with a microwave exposure of 60 seconds.

Status of electromagnetic heating for enhanced heavy oil/bitumen recovery and future prospects

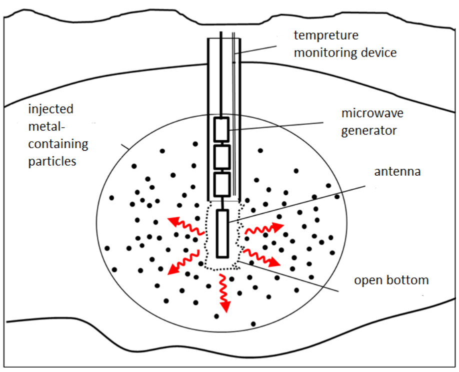
Al-janabi Omar Abdulamer
Kazan federal university
*Corresponding author: omar.ajabd@gmail.com

Keywords: electromagnetic heating

Several thermal methods are used worldwide to enhance oil recovery from heavy and extra heavy oil reservoirs, traditional thermal enhanced oil recovery technologies are ineffective for recovering heavy oil reservoirs or deep wells. Microwave heating is one method of controlling the amount of heat entering a tank in a controlled manner. Various experiments have shown that the success of microwave heating generation is highly dependent on initial reservoir parameters such as initial water saturation and salinity.

An analysis of the current level of research in the field of microwave exposure for the processing and production of hydrocarbons has been carried out. Particular attention is paid to the use of various catalysts that provide the intensification of various reactions, provide a high degree of processing or reduce viscosity in the production of high-viscosity oil. A number of works report on the use of nanoscale catalysts based on transition metals capable of absorbing microwave radiation. Among these catalysts, the core-shell catalyst stands out, which is characterized by a higher ability to absorb a microwave field compared to bulk catalysts.

Based on the analysis of literature sources, for preliminary experiments on microwave processing of rock samples containing high-viscosity oil, magnetite with a dispersion of no more than 200 nm was chosen. Four experiments were carried out under different conditions at the setup of the Institute of Applied Physics, Russian Academy of Sciences (Nizhny Novgorod). The composition of the extracted oil and the content of non-extractable organic substances were studied. A decrease in the content of asphaltenes in the produced oil and a decrease in the molecular weight of non-extractable organic matter in the composition of the rock have been established.



A system of microwave generators connected to a slot antenna via optical fiber is used. The slot antenna is placed at the bottom of the well without a casing (with an open bottom). In order to intensify and increase the coverage of the formation, a suspension of metal-containing particles (or an oil-soluble precursor solution from which metal-containing particles are formed during formation heating) is first pumped.

To develop a method for intensifying microwave exposure during oil production using magnetite nanoparticles.

* Analyze sources on the use of microwave stimulation catalysts for the production of high-viscosity and shale oil.

* Determine the composition of oil under various options for exposure to a microwave field in the presence and in the absence of magnetite nanoparticles.

* Propose a technical solution to optimize the method of using microwave radiation for the production of high-viscosity oil.

The analysis of sources on the use of microwave stimulation catalysts for the production of high-viscosity and shale oils was carried out.

The process of microwave absorption in the presence of magnetite nanoparticles for the composition of high-viscosity oil has been studied.

The oil composition was determined for various variants of exposure to a microwave field in the presence and in the absence of magnetite nanoparticles. In the presence of a catalyst, the content of resins and asphaltenes decreases.

A technical solution is proposed to optimize the method of using microwave radiation to produce high-viscosity oil. The new method is based on the injection of metal-containing nanoparticles into the reservoir to increase the coverage and increase the conversion of resins and asphaltenes.

THEOR BAKU

THERMOCHEMICAL FLUIDS FOR WELLBORE TREATMENT

New Technology for Thermal and Chemical Impact on Layer

Natiq M.Safarov[a*] , Gafar G.Ismayilov[b], Fidan B.Ismayilova[b]
[a] Oil&Gas Scientific Research Institute, SOCAR, Azerbaijan
[b] Azerbaijan State Oil and Industrial University, Azerbaijan
[*] Corresponding author: E-mail: natik_safarov@mail.ru

Keywords: hydrocarbon reserves; high viscosity oils; asphaltene-paraffin-resin combinations; thermal and chemical impact technology; exothermical reaction.

The article considers studies devoted to application of new technologies for thermal and chemical impact on layer in aim to increase productivity in oilfields of Azerbaijan producing oil with abnormal properties and asphaltene-paraffin-resin contents. Problems of evaluation of optimal amount of components required for injection into the layer for realizasion of exothermical reaction of chemical reagents selected on the basis of laboratory tests, as well as evaluation of needed polyizobutilene concentration and its optimal ratio with hydrochlorical acid have been considered. According of results laboratory and oilfield analysis, synergetic (thermal and chemical) impact technology is proved as efficient and is recommended for use in oil fields of Azerbaijan with high viscosity heavy oil and bitumen production.

Thermogas-chemical Method of Oil Reservoir Development

Khidir M. Ibrahimov
"OilGasScientificResearchProject" Institute, SOCAR, Azerbaijan;
* Corresponding author:khidir.ibrahimov@socar.az

Keywords: thermogas,reservoir development,displacement ratio, chemical method

To increase oil recovery in the field, a method has been developed that includes thermal and gas stimulation of the reservoir by sequential injection of aqueous solutions of potassium salt and sulfuric acid into the reservoir. Light oil or gas condensate is injected into the reservoir before the aqueous sulfuric acid solution is injected. After injection the aqueous sulfuric acid solution, air is pumped into the formation with subsequent water pushing, while a 16% aqueous potassium bichromate solution is used as an aqueous solution of potassium salt.

Injection of chemical reagents provides the beginning of the oxidation process, its uniform distribution in the bottomhole zone, expansion of the area providing the beginning of the process, alignment of the front of exothermic reactions zone movement.

Increased reservoir temperature increases oil mobility, reduces viscosity and interfacial tension, which facilitates the movement of oil to production wells. Sulfuric acid pumped into the reservoir, the products received as a result of exothermic reactions and increase of the medium temperature contribute to melting and washing asphaltene-resin-paraffin deposits from the rock surface. The effect of the injected and generated acids on the rock increases with increasing temperature, which leads to an increase in the permeability of the porous medium.

Conclusions

1. The method of oil reservoir development based on low-temperature oil oxidation as a result of exothermic reaction initiation and subsequent injection of oxygen-containing gas into the reservoir is proposed.
2. It has been established that as a result of exothermic reaction the temperature in the porous medium rises above 200^0C, and the increase of displacement ratio reaches 19,7 %.
3. The analysis of gas component composition showed the presence of carbon dioxide and absence of sulfur dioxide and oxygen in the selected samples, which ensures the safety of technology

A new thermochemical method for oil displacement from formation.

Malik G. Abdullayev*, Shahin Z. Ismaylov, Elman Kh. İskandarov, Shafaq A. Habibullayeva, Saleh A. Rahmanov.
Azerbaijan State Oil and Industry University (ASOIU)
* Corresponding author: malik.abdullayev.52@mail.ru

Keywords: layer, composition, temperature, acid, oxidizer, alkali, alcohol.

A new thermochemical method has been developed for the compression of oil from the reservoir. It is known that certain difficulties arise in the development of fields that are in the final stage of development. So, at the last stage, with the drop of both pressure and temperature in the layers, sharp changes occur in the rheological parameters of the oil and the layer. As the temperature drops, the oil's viscosity and specific gravity increase, making it difficult to squeeze them out of the reservoir using traditional methods. It becomes difficult to filter it in the formation, as a result, the production of the wells decreases, thus the oil production coefficient decreases. In this case, there is a need to influence the formations by thermal methods to ensure the improvement of oil percolation in the formation. However, if only hot water is the basis of these heating methods, it is doubtful that the obtained results will be highly effective. Because, although hot water lowers the viscosity of oil by raising the temperature in the formation, it cannot lower the surface tension forces there. Therefore, it is appropriate to apply thermochemical methods to achieve both heat generation in the formation and reduction of surface tension forces. For this purpose, a composition consisting of certain acids, oxidants, alkalis and alcohols has been prepared, the reaction that occurs when the components of this composition meet each other occurs with the release of heat, and the product of the reaction creates an acid and solubility environment, which increases the temperature in the formation, on the one hand, and the oil although it lowers its viscosity, on the other hand, it penetrates into the composition of oil, weakens the surface tension forces between oil-water and oil-rock, pulls oil from the rock surface, and causes it to be forced out of the formation. As a result, it leads to an increase in oil production and an increase in the final oil yield coefficient. These works have been confirmed by laboratory studies.

Composition for thermochemical treatment bottomhole zone of an oil reservoir.

Shahin Z. Ismailov, Malik G. Abdullayev*, Shaiddin Z. Ismailov, Arzu V. Sultanova
Azerbaijan State Oil and Industry University (ASOIU)
* Corresponding author: malik.abdullayev.52@mail.ru

Keywords: bottomhole formation zone, permeability, oil, water, chromic anhydride, methanol, turpentine.

In this article, a new composition has been developed, where the mission of the work is to increase the efficiency of treatment by injecting a heat carrier mixture into the bottomhole zone, which increases the dissolving ability of the composition, the rate and volume of dissolution of hardly soluble rocks during treatment of the bottomhole zone of wells, as well as the ability to deeply penetration into the formation.

When this composition enters the oil-saturated pores of the formation, turpentine, as a good solvent, significantly reduces the stability of unwanted oil-acid emulsions, and the further reaction of an aqueous solution of chromic anhydride with methanol is enhanced due to the presence of turpentine in the bottomhole zone. The proposed composition reacts with aromatic hydrocarbons, as well as saturated hydrocarbons (paraffins). As a result of chemical reactions, various acidic esters are obtained - aldehydes, ketones, etc., which can reduce the interfacial tension, increase the inhibiting effect, and also dissolve heavy oil components in the pores well and restore the permeability of the bottomhole zone, thereby improving the flow of oil from the reservoir to the well.

Prospects for the development of methods for influencing the bottom-hole zone of the well formation to intensify the production of high-viscosity oil in the fields of tatarstan

Smelov Aleksandr*, Guzel Ganieva
Kazan (Volga Region) Federal University
* Correspondent author:Smelov.99@mail.ru

Keywords: Acid treatment; foam acid treatment, borehole; acid

The paper considers the analysis of the methods of the effectiveness of the use of acid treatment of PP. The main points affecting its effectiveness are highlighted, the definition of the most significant ones is determined as a result of laboratory tests.

At the present stage of development of the complex of oil and gas operations, a significant decrease in oil production levels is noticeable with a widespread increase in the water content of the extracted products and a deterioration in the structure of recoverable hydrocarbon reserves. In such a situation, the best solution is advanced technologies for processing the bottom of the well. One of the traditional methods is hydrochloric acid treatment. However, repeated acid treatment is not always an effective method. The acid dissolves the rock with each impact, thereby low-permeable layers are not involved in the development. For effective treatment, surfactants are added to the acid composition. Surfactant is used as a blocking agent in highly permeable channels, thereby allowing acid to involve low-permeable layers in the development. This method of processing of PPD involves the use of acid compositions injected into the bottom-hole zone, and a further reaction of dissolution of rocks or a colmatating agent with the widespread removal of reaction products into the bottom of the well, and subsequently to the surface, by washing operations.

The thermochemical method is also known. The essence of this method lies in the interaction of the acid composition with the gas-generating solution and with the instantaneous generation of foam, the temperature of the latter reaches up to 80 °C.

The claimed technologies have been tested in the laboratory. In the course of research, it was determined that the effectiveness of each treatment method mainly depends on: the lithological composition of rocks, the residual concentration of reacted acid, the rate of acid injection into the reservoir, the volume of acid composition and the reaction rate. Also, during the tests, the dependence of the multiplicity of the half-life and the temperature of the foam on the ratio of concentrations and volume was revealed.

The claimed method of thermal acid treatment due to the exothermic reaction allows for deeper processing of the formation.

Determination of the heat capacity of two-phase systems according to the additivity law

Mirza A. Dadashzade, Inglab N. Aliyev*, Pervane Sh.Ismayilova.
Azerbaijan State Oil and Industry University (ASOIU)
* Corresponding author: inqilab.aliyev@asoiu.edu.az

Keywords: production well; temperature; reservoir fluids; rock; water injection.

Practice shows that the temperature around the drilling and production wells is of great interest from the point of view of the choice of design, preventing the precipitation of heavy fractions (paraffin, resins, tar).

Literature analysis has shown that the temperature of the elements of drilling and production wells is determined with sufficient reliability by the method of successive changes in the stationary state.

To select downhole equipment, both during drilling and operation, it is necessary to determine the temperature values for the wells.

The performed calculations show that the change in the temperature of the hydrocarbon along the wellbore during flow operation is considered in three cases of filling the annulus.

To clarify the temperature, calculations must be carried out step by step, dividing the length of the lift into certain intervals.

Note that similar temperature calculations are also made in injection wells when hot water is injected into the reservoir. At the same time, it should be noted that when injecting hot water, it is important to maintain the temperature of the injected water above the formation temperature.

The temperature of the water injected into the reservoir from the wellhead to the bottom of the well is determined from the joint solution of the equations of thermodynamics and heat transfer.

Literature analysis shows, that in order to calculate the temperature of produced or injected water, it is necessary to know the parameters of the thermos-physical properties of well production, reservoir fluids, cement stone and surrounding rocks. In a particular case, a water-gas-oil mixture moves in a production well, the concentration of phases and components of which changes as it moving upwards to the wellhead. A similar mixture system is located in the annular space between the pipe strings and in the pores of the rocks that make up the reservoir.

Thermochemical fluids of delayed action with the application of a viscoelastic surface-active substance for treatment of the borehole formation zone

V.A. Milyutina*, V.V. Andriyashin, G.R. Ganieva, H.E. Belaid, M.S. Vlasenko
Kazan Federal University
* Corresponding author: mom500090gmail.com

To date, various thermochemical compositions have been developed and used for treating the bottomhole formation zone (BFZ). The most effective in solving the problems of cleaning the bottom-hole zone from organic deposits are thermochemical compositions. thermochemical fluids (TCF) are aqueous solutions of two inorganic salts, during the reaction a large amount of gas and heat are released. The components of thermochemical fluids are most often mixtures of nitrogen-containing compounds capable of entering into a redox reaction with each other.

The idea of the method of thermochemical treatment (TCT) using TCF is to creat a kind of thermochemical gas generator, during operation, a chemical reaction occurs with the release of a large amount of gas and heat. Both of these factors together create favorable conditions for cleaning the bottomhole zone from asphaltene-resin-paraffin deposits (ARPD), increasing well productivity and oil recovery.

The reaction of ammonium nitrate with sodium nitrite is described by the following equation:

$NH_4NO_3 + NaNO_2 \leftrightarrow NH_4NO_2 + NaNO_3$

$NH_4NO_2 = N_2 + 2H_2O + Q.$

As a result of the reaction between the components of the TCF, an ion exchange reaction occurs at the first stage, with the formation of ammonium nitrite, which in turn, due to the decomposition, forms a large amount of an inert gas - nitrogen and heat.

An important step in using the TCT method with the use of TCF is the selection of the initiator of the chemical reaction.

In this work, we study several initiators that make it possible to increase the onset time of the TCF reaction up to two hours, as well as the use of a viscoelastic surfactant (surfactant) together with an initiator based on carboxylic acids.

It has been determined that higher carboxylic acids make it possible to achieve a reaction delay time of up to two hours, while lower carboxylic acids, such as formic and acetic acids, do not provide sufficient time to delay the start of the reaction, but they have sufficient potential to create a technology for thermal foam acid treatment of the bottomhole zone.

Now, thermofoam-acid compositions based on inhibited 24% hydrochloric acid are known. However, these compositions have a number of disadvantages, among which - are the resinous ability of concentrated hydrochloric acid in relation to oil, the need to use expensive stabilizers of ferric ions (Fe^{3+}) and high-temperature corrosion inhibitors.

The main advantages of using lower carboxylic acids together with a gas-generating thermochemical composition are the slow reaction rate of the acid with the rock, low corrosiveness, and high stabilizing properties in relation to ferric ions (Fe^{3+}). The combined use of lower carboxylic acids and an amphoteric viscoelastic surfactant makes it possible to achieve a high washing capacity of thermofoam-acid compositions, simultaneously with high foam expansion values, which in turn makes it possible to involve low-permeability sections of the reservoir in the treatment.

Research and engineering of new methods for designing acid jobs in carbonate reservoirs utilizing numerical simulations and core laboratory data

Andrey Sharifullin*, Marat Sitdikov, Ruslan Rabaev
Ufa state petroleum technological university, Russian Federation
* Corresponding author: tetacomufa@gmail.com

Key words: acid stimulation, wormhole formation process, acid compositions, acid job design.

Objective and scope of work - improving the efficiency of acid job simulations in heterogeneous carbonate reservoirs and defining approaches to selecting the best acid compositions and injection patterns using physical and chemical modeling and numerical modeling.

Methods, technologies, process description: flow tests were run involving acid treatment of natural core samples to study the process of wormhole formation and channeling in laboratory conditions; various approaches were compared for mathematical characterization of the wormhole formation process in core samples; flow test results were used to calibrate the numerical models of acid stimulation and to compare their performance; to prove the efficiency of the engineered numerical models field tests were performed including production tests and well logging prior to and following the acid jobs.

Results, conclusions: laboratory data interpretation provided the results for history matching including the initial parameters of the tests with injection rates for the analyzed acid compositions acting on core samples and characteristics of wormhole formation speed in carbonates – injected acid volume versus time to the breakthrough.

Engineering resulted in a general numerical model describing the designed acid job including multi-phase 2D flow of injected fluids with different rheological properties downhole into the heterogeneous reservoir and acid-rock reaction accompanied by heat release. Field tests provided more accurate data to maximize the reliability of the acid job design using the general numerical model.

Innovation and achievements: the analysis of the research results identified key parameters contributing to the efficiency of acid compositions for the given reservoir conditions and defined their range of applicability.

The general numerical model describing the process of acid stimulation of the reservoir was first engineered and then field tested.

The findings of the research were used to create the numerical database with acid composition properties and to maximize the accuracy and reliability of calculations in flow simulations of acid jobs.

ThEOR BAKU

Determination of reservoir pressure distribution and temperature when exposed to a hot agent on the formation with non-Newtonian oil

Samira V. Abbasova, Gulbahar G. Mammadova, Elshan E. Abbaszade*.
Azerbaijan State Oil and Industry University (ASOIU)
*Corresponding author: *aelshan493@mail.ru

Keywords: non-Newtonian oil; hot agent; initial pressure gradient; pressure; temperature.

Among the various methods of enhanced oil recovery of non-Newtonian oil, a special place is occupied by thermal methods in various modifications. These methods generally reduce the viscosity of the oil and stimulate its flow to the well even at small pressure gradients that increase the initial fluid shear pressure gradient. However, due to the high energy consumption of these methods, it is necessary to carry out preliminary evaluation calculations to determine the effectiveness of their application.

Reservoir pressure and temperature are significant parameters among the geological and technological factors that affect the development and operation of the field. Their determination based on the formulation and solution of hydrothermodynamic problems is of particular relevance. Moreover, knowledge of their changes in the reservoir, depending on the development of the field, can play a special role, from the point of view of taking into account the real thermobaric conditions, in particular, when solving problems of increasing well production using thermal stimulation methods.

Reservoirs with non-Newtonian oil are characterized by an initial shear gradient, which must be taken into account when designing their development. In connection with this need, the article considers the problem of determining reservoir pressure and temperature when a non-Newtonian oil reservoir is exposed to a hot agent. To determine these indicators, iterative schemes are proposed.

SUPERCRITICAL FLUIDS INJECTION (WATER, CO2, HYDROCARBONS)

Efficient Multifunctional Systems for Improving Oil Recovery, Energy Efficiency and Environmental Sustainability

Vladislav A Naletov[a*], Mikhail B Glebov[b], Viatcheslav V Kafarov[c], Alexey Yu Naletov[d]
[a] Mendeleev Russian Chemical and Technological University, Moscow, Russia
[b] Mendeleev Russian Chemical and Technological University, Moscow, Russia
[c] Industrial University of Santander, Santander, Colombia
[d] Mendeleev Russian Chemical and Technological University, Moscow, Russia
[*]Corresponding author: jacen23@yandex.ru

Keywords: process design; carbon dioxide; energy saving; enhanced oil recovery; exergy efficiency;

Recent events on world energy markets clearly indicate: unrealistic expectations on investment in renewable energy can lead to a shortage of energy supply in every industry and every corner of the world. This was also stated in the World Energy Outlook, published by the IEA (International Energy Agency) in 2021. Meanwhile demand for fossil fuels, including oil, gas and coal, is growing and their share in the overall energy supply in not expected to fall lower that 75%, as shown in IEA's forecasts and information from OPEC's secretariat.

In view of this, along with current environmental and sustainability policies, experts now focus on two priority research areas within the global economy:

- Energy efficiency and energy saving (including cogeneration and polygeneration)
- Carbon Capture and Storage (including enhanced oil recovery applications)

Any technology or system, developed without focusing on these strategic points, will likely lead to even worse problems for the environment, followed by increased air, water and soil pollution and global climate change.

Current oil production, transport and refining technologies have to be drastically redesigned in order to address these relevant issues. This also constitutes the use of high-efficiency multifunctional systems.

The main theory behind process design could be based on general systems theory, which outlines the main principles of creating complex systems in technology by improving their organization.

The report details a pilot plant designed for improving the profitability of oil production, energy recovery and reducing carbon dioxide emissions in application to offshore Artic oilfields.

The proposed solution can be scaled to a larger power production capacity. It is based on systems consisting of: a power module that uses the Brayton cycle combined with a Rankine cycle operating on low-boiling working fluids; a module for carbon dioxide capture from flue gases; and a module for producing carbon dioxide in a liquid or supercritical state for improving oil recovery as well as carbon sequestration.

Process simulations and efficiency calculations have shown an improvement over existing solution.

New ATR-FTIR Spectroscopy Approach for Determination of Wax Appearance Temperature at High-Pressure Gas Conditions

Anton Sergeevich Shalygin[a,b*], Evgeny Vladimironich Morozov[b,c], Oleg Nikolaevich Martyanov[a],
[a]Boreskov Institute of Catalysis, Siberian Branch of the Russian Academy of Sciences
[b]Institute of Chemistry and Chemical Technology, Federal Research Center "Krasnoyarsk Science Center of Siberian Branch of the Russian Academy of Sciences"
[c]Kirensky Institute of Physics, Federal Research Center "Krasnoyarsk Science Center of Siberian Branch of the Russian Academy of Sciences"
[*]Corresponding author: shas@catalysis.ru

Keywords: ATR-FTIR spectroscopy; wax; WAT; CO_2 pressure

Wax appearance temperature (WAT) is critically important parameter characterized crude oil and other oil products (wax solution, fuels, bitumen, asphalt binders). The determination of WAT and other parameters at high pressure under such as gases: nitrogen, natural gas, and CO_2, is essential to the development of the application of EOR methods based on gas injection flooding. Most of the available methods for determining WAT work at atmospheric pressure, and the study at high pressure in situ requires their significant modification. The FTIR spectroscopy method is quite widely used to study n-alkanes and phase transitions in their mixtures. However, there is no information on the use of the high-pressure FTIR spectroscopy for measuring WAT and phase transformations. At the same time, a variation of the method of ATR-FTIR spectroscopy has proven itself well in the study of systems in the in situ mode at high gas pressure.

In situ ATR-FTIR spectroscopy was first used to study a solution of wax in n-dodecane at various pressures of CO_2, nitrogen, and temperatures. It has been established that the ATR-FTIR spectroscopy can be used to reliably determine of WAT in the presence of CO_2 and nitrogen. To determine WAT at high pressure, using traditional calculation methods that are based on changes in the rocking mode band of CH_2 groups. In addition, it was found that the temperature dependence of the peak intensity of the spectral band characteristic of CO_2 dissolved in the system exhibits a characteristic break. This can serve as an additional indicator of WAT, which increases the accuracy of the measurements and the reliability of determining the temperature of the onset of paraffin crystallization.

Using the presented method, it was confirmed that with an increase in gas pressure, the temperature of the onset of paraffin crystallization decreases. This agrees well with the literature data on thermodynamic modeling of the phase behavior of n-alkane mixtures and experimental studies of differential scanning calorimetry [3].

The research was performed with the financial support of the Russian Science Foundation (project no. 21-13-00171, http://rscf.ru/project/21-13-00171/).

Screening, Evaluation, and Ranking of Azerbaijani Reservoirs Suitable for CO_2-Flood EOR and Carbon Dioxide Sequestration

Vusal Karimov, Farad Kamyabi
Baku Higher Oil School, Azerbaijan

Keywords: sequestration; enhanced recovery; CCS; screening; CO_2 injection.

CO2-flood EOR has been implemented since the 1970's, and today CO2-EOR is regarded as a considerably established application in oil and gas industry. CO2-flood EOR is performed by injecting CO2 to the reservoir in which it can change residual oil characteristics, and allow oil to move. With the aid of the miscible CO2-flood, the lifetime of the field can be extended up to 25 years, and additional 20% OIIP can be recovered. Furthermore, besides improving oil recovery, it makes possible to store considerable amounts of CO2 in the formation.

CO_2-flood EOR was used widely in USA in the last century, and now is becoming popular in some countries. Azerbaijani reservoirs provide ostensibly optimal position for CO_2-flood EOR. Relatively deep reservoirs with low API oil in Azerbaijan can be selected for CO_2-flood EOR. South Caspian Basin also generates huge volumes of CO_2 that is at the present time discharged directly into the atmosphere. Applying CO_2-flood EOR can have influences on both CO_2 footprint of oil and gas companies in Azerbaijan and oil recovery of South Caspian Basin. In spite of these factors, there is considerable literature shortage regarding with CO_2-flood applicability in South Caspian Basin.

The main objective of the study provided is to give information to the public, energy companies especially petroleum industry about importance of CO_2-flood EOR in Azerbaijan. A screening investigation was performed on the reservoirs in South Caspian Basin to check feasibility of CO_2 injection to the oil producing reservoirs. In order to checking candidates for CO_2 flood EOR an algorithm for screening was implemented to the South Caspian Basin by writing a user friendly VBA code based on machine learning approaches by implementing five appropriate screening criteria where the user could predict he potential result of an EOR method by inputting the required data, mainly rock and fluid properties. This code has been benchmarked by EOR Survey in the North Sea. Throughout the study two productive series of Azerbaijan (Balakhani Vlll and Pereriv B) were checked for CO_2 flood EOR suitability, and both of them were detected technically good candidates (93% feasibility) for CO_2 injection and sequestration. The methodology presented herein for screening oil reservoirs for CO2-EOR and CO2 storage proved that generally, South Caspian Basin has technically good candidates for CO2-flood EOR, and CO_2-flood EOR can be applied to decrease carbon footprint and increase oil production rate in Azerbaijan.

Evaluation of Reservoirs for Carbon Dioxide Sequestration

Alakbar Alakbarov*
Azerbaijan State Oil and Industry University, Azerbaijan
*Corresponding author:alakbar.alakbarov@outlook.com

Keywords: carbon dioxide; enhanced oil recovery; sequestration; flood.

Carbon dioxide injection into productive layers has been widely used around the world since the 1970's and is among the most advanced methods in the oil and gas industry today. This method injects carbon dioxide gas into the productive zone and changes the chemical composition of the oil there including changes in its physical properties and as a result stuck to the pores the remaining oil is activated. With the help of this method, the life of the field can be increased up to 25 years oil yield can increase up to 20 percent. In addition to the increase in oil yield, this method lays down CO_2 allows it to act as a reservoir, and carbon dioxide gas can be stored in the porous rocks.

This method used to increase oil yield was widespread in the United States in the last century. It has become one of the methods that is widespread and currently widely used in several countries. Azerbaijan's fields are geologically located in an optimal position for carbon dioxide injection. These fields have relatively deep oil-rich zones with low API can be selected as a candidate for the process. The South Caspian oil and gas basin is large generates large amounts of carbon dioxide, and that this gas is released directly into the atmosphere. In addition to the increase in oil yield by applying the method of injecting carbon dioxide gas into the fields, reducing the carbon footprint of oil companies in Azerbaijan can also be achieved. Despite the above-mentioned facts, in the South Caspian oil and gas basin the literature on carbon dioxide injection into productive layers is insufficient.

The aim of the conducted research was to assess the suitability of Azerbaijan reservoirs in the South Caspian Basin will undergo CO_2 injection. The goal was achieved using relevant data and technical parametric filtering of oil layers in the field.

Thermochemical methods to control dispersed fluids flow for enhanced oil recovery

Geylani M. Panahov[a], Eldar M. Abbasov[a*], Vusale D. Balakchi[b]
[a]Institute of Mathematics and Mechanics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan
[b]Oil and Gas Institute, Azerbaijan National Academy of Sciences, Baku, Azerbaijan
[*]Corresponding author: eldar.abbasov@imm.az

Keywords: carbon dioxide; thermal-gas methods; displacement; steam injection; viscosity

With the changing reserve structure under oil fields development and the increasing share of hard-to-recover hydrocarbons, tertiary thermal-gas methods of oil production are of particular relevance. These methods include technologies based on displacement of residual oil by steam or hot water injection combined with in-situ generation of carbon dioxide CO_2. In EOR the carbon dioxide is mainly used in continuous injection processes as well as in alternate injection of water and CO_2 slugs. At the same time the interest to the “wet CO_2” injection which is a combination of thermal stimulation and gas injection has increased recently. The report reflects the results of studies to develop a new technological solution for efficient production of in-situ “wet” carbon dioxide. The saturation of the generated CO_2, achieved by pre-injection of gas-generating and thermal agents in the reservoir (the slugs of coolant - steam or hot water) provides the required thermodynamic conditions and increases of the reservoir sweep efficiency, including through the fractality of the displacement front.

Research includes laboratory experiments on oil displacement by steam (hot water); carbon dioxide (CO_2) and combined alternating injection of steam (hot water) and gas-forming aqueous chemical solutions. The results of experiments confirmed the increase of oil displacement efficiency under combined stimulation of CO_2 and steam (hot water) by 16 % on the average in comparison with separate displacement of oil by carbon dioxide and thermal agent.

The process capability provides to control the generation rate and the volume of CO_2 gas released, while the thermobaric conditions and the salinity of the gas-extracting solutions - phase state of the carbon dioxide. Released during the reaction, carbon dioxide segregates into the upper zones of the fluid-saturated porous medium, dissolving into the oil, along with a change in viscosity it contributes to increasing its density and thereby stimulates the process of density segregation. Thus, the oil saturation at the front end of the displacement front increases, which ultimately leads to an increase in the oil recovery factor.

Within the framework of the above-described mechanism of combined injection of carbon dioxide and thermal agents, a new technological solution is proposed based on an effective method of producing “wet” carbon dioxide by generating it in formation conditions, which provides sweep efficiency improvement.

Laboratory Modelling of Thermal Method for Source Rock with Fracture

Evgeny Popov*, Pavel Grishin, Alexey Smirnov, Alexey Chremisin
Center of Petroleum Science and Engineering, Skolkovo Institute of Science and Technology, Russia
* Corresponding author: E.Popov@skoltech.ru

Keywords: thermal method, hydraulic fracture, thermal conversion of the solid organic matter, conductivity of fracture

Today, for increasing of the oil production the technologies are being actively developed for heating of the reservoir with source rock to temperatures of 300-400°C. A solid organic matter in the source rock converts into mobile hydrocarbons at this temperature and the mobility of heavy oil components increase. Usually the hydraulic fracturing is used as a secondary method for oil production increase with expansion of the stimulated formation volume with proppant fixation of the fractures. The subsequent thermal treatment of the formation with injection of a heating agent increases the reservoir temperature and uses a previously formed system of the fractures. The changes of the reservoir properties of the rock under the heating and thermal transformation of the solid organic matter, which is a part of the rock, changing its state to the liquid, affect to efficiency of the recovery method. Moreover, the changes of the mechanical properties of the rock, which are associated with the migration of hydrocarbons and pore space increasement, impact to oil recovery.

The ordinary laboratory equipment for fracture conductivity testing could not create such high pressure and high temperatures (HPHT) simultaneously for investigation of the fracture conductivity for source rock during organic matter transformation.

The study represents new approaches for the laboratory modelling of thermal treatment of the source rock at temperature of 300-400°C and reservoir pressure of 25 MPa and for investigation of behavior of the system consisted of rock, proppant and heating agent. Laboratory experiments were conducted in HPHT autoclave with CO_2 and water as the heating and extraction agents. An unique small cell for the standard cylindrical core plug were developed and tested. A formation model consisted of the source rock with total organic carbon of 4-15% and high strength ceramic proppant.

As a result, the laboratory testing allowed to compare the efficiency of two agents for the thermal EOR at temperatures of 350°C. Advanced analysis of the rock represented the distribution of the residual hydrocarbons (HC) in the rock and determined conversion value of solid organic matter. Both agents demonstrated high efficiency for HC extraction from the rock. Fracture conductivity decreased by two times at temperature rising from 120 to 350°C. The main reasons of conductivity decrease were the rock destruction during hydrocarbons coming out and the indention of the proppant.

Experimental Study into the Effect of Temperature on the Evaporation of Retrograde Condensate with Different Gas Mixtures in the Bottomhole Zone of the Production Well

Vugar M. Fataliyev [a*], Natig N. Hamidov [b].
[a]. Department of Petroleum Engineering, Azerbaijan State Oil and Industry University, Azerbaijan.
[b]. Oil Gas Scientific Research Project Institute, SOCAR, Azerbaijan
[*]Corresponding author: vugarfataliyev@yahoo.com

Keywords: Phase transformation; Retrograde condensation; Gas injection; Condensate vaporization; Dew point pressure.

In this paper a laboratory study was carried out with the purpose of estimating the temperature impact on the gas injection process for vaporizing retrograde condensate accumulated in the well bottomhole zone. Usually, this phenomenon occurs due to development of gas-condensate reservoir in depletion regime. It is known, that the condensate blockage causes serious issues including reducing well productivity and resulting in fluctuation of downhole and wellhead pressures, creating unsafe condition for well operations.

The mechanism has been widely investigated and described before. The logic is when the pressure in the well drawdown region of reservoir drops below retrograde dew point pressure, liquid accumulation takes place in the reservoir section, close to wellbore zone. Also, it reduces relative permeability for gas and the gas velocity in the wellbore drops according with this transformation. It could continue and drop further reaching to a critical level. This is a state, also, hydrocarbon liquid begins to accumulate in the well and the well flow can undergo annular flow followed by a slug flow regime. This well liquid loading process increases bottomhole pressure and reduces gas production rate additionally. Low gas production rate will cause gas velocity to drop further and eventually the well can cease producing.

Several measures can be taken to mitigate liquid accumulation in the near wellbore region and reduce the liquid loading problem in gas-condensate production wells. For example, it is possible to monitor and adjust drawdown pressure for mitigating liquid drop-out in the well by using automated control system but this method could help only if reservoir energy enough to support the intention of the method. One of the methods that promise successful results base on nowadays studies is gas injection into the downhole region of the production well. The main principle of this approach is to evaporate hydrocarbon condensate turning it into gas phase again. But there are number of factors can impact on effectiveness which should be considered closely. It includes: injection gas composition, gas solubility in the liquid, physical nature and being economical viable.

Taking into account all mentioned elements above, specific laboratory equipment was constructed and tested for performing an experimental investigation by modeling the gas injection into the reservoir when it is in significantly depleted state. For determining an effective vaporizer, different gas mixtures (natural gas contains different CO_2 and N_2 mole fractions) have been tested. Except learning standard parameters as; physical and volumetric properties, retrograde condensation condition, gas/condensate ratio, dew point pressures of gas-condensate fluids after injection “dry” gas mixture to support accuracy, also, the impact of temperature on volume of vaporized and extracted liquid hydrocarbon from “reservoir” was investigated. The reservoir fluid was recombined based on samples from Azerbaijan natural gas-condensate reservoir “Bulla-deniz”.

The research shows that CO_2 injection is more effective than natural gas and the gas is mixed with nitrogen but learning the same process at different temperature it was discovered that the effectiveness of the injected agent (gas mixture) significantly depends on temperature range. In other words, gas-condensate systems which were combined with different CO_2 and N_2 fractions could behave unexpectedly with depend on temperature interval. That is reason, during selection of effective vaporizer downhole temperature of the injection well should be considered.

The work also, provided a field case study base on assessing the performance of the real gas injection facility and gas injection wells. It was determined that during gas injection, the injection temperature is not taken into account, unlike its injection pressure. However, this can be achieved very easily without spending extra energy because natural gas presents an increase of temperature when it is compressed to injection pressure. It was confirmed after this field case studies that, for example, it is possible to get a temperature of 190^0C at the outlet of the gas compressor for injecting gas into the "Bulla-deniz" gas-condensate reservoir where 10-12MPa injection pressure is required. Injecting gas with high temperature could help to unload cooling system at the discharge of the injection compressor and to increase efficiency of injection gas.

PRODUCTION OF UNCONVENTIONAL RESOURCES (TIGHT OIL, SHALE OIL, TAR SANDS, ETC.)

New Technical Means for Extraction of Heavy Crude Oil

Anatoliy Andreevich Isaev *
Sheshmaoil Management Company LLC, Russian Federation
*Corresponding author: isaeff-oil@yandex.ru

Abstract: To reduce the adverse effects of viscous friction forces on the efficiency of artificial lift under the same conditions of well operation, performance of the unit, and properties of formation fluids, the effective viscosity of the product, as well as the stroke rate of the rods and flow rate of the product in the elevator should be as low as possible, and the area of the passage section of the latter should be as large as possible (this is true for crude oils without rheopectic properties, that is, those that do not texture at low rates with a sharp increase in viscosity). Extracting products via the production string without tubing is the most radical option to implement this approach which reduces the estimated hydrodynamic resistance tenfold compared to that in the tubing Installations have been developed for tubingless well operation with a packer (fig.1) and without it. Implementing these installations at 42 wells proved their economic and technical efficiency.

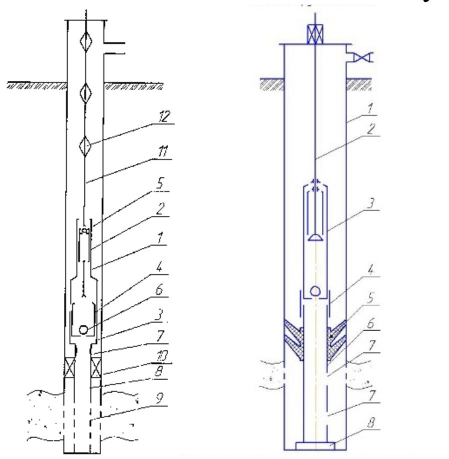


Fig.1.

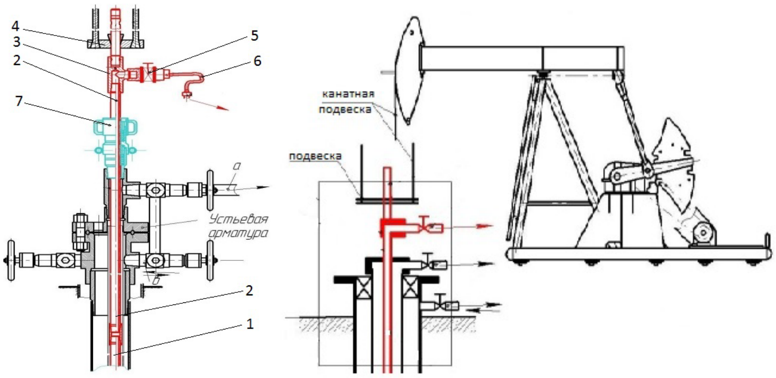


Fig.2

Huff and Puff Gas Unconventional Enhanced Oil Recovery Technique in Unconventional Low Permeability Hydrocarbon Reservoirs

Rashad Nazaraliyev
Baku Higher Oil School, Azerbaijan

Keywords: huff and puff; gas EOR; low permeability unconventional reservoirs; tight oil.

The conventional oil reserves are going to deplete with the growing energy consumption. Unconventional petroleum resources including light tight oil has attracted attention to meet the rising energy demands and are likely to have a significant impact on energy supply. According to Joe Leimkuhler et al., the world economy will continue to require a steady supply of hydrocarbons even as the usage of renewables grows (Leimkuhler, J. & Leveille, G., 2012; Song, C. & Yang, D., 2013).

The tight oil reserves contribute to significant amount, which globally may vary between 335 and 345 billion barrels (U.S. Energy Information Administration (EIA), 2013). However, the current problem is that conventional methods are unable to extract hydrocarbons from tight reservoirs due to their associated reduced permeability. Tight reservoirs are source rocks or reservoirs with organic rich contents, i.e., any rocks having low permeability, e.g., sandstone, limestone, and shale (Canadian Society for Unconventional Resources (CSUR), 2019).

The primary recovery from tight reservoirs is too low, approximately 5 to 10% of STOIIP in tight deposits, even though production is through massively fractured long horizontal wells, which implies necessity of the application of enhanced liquid recovery methods in these reservoirs. The results from numerous numerical and laboratory studies show that huff-n-puff EOR can be a solution to increase the recovery from tight oil reservoirs (Christensen, J. R., Stenby, E. H., & Skauge, A., 1998; Shoaib, S. & Hoffman, B. T. 2009). Following the achievements in Eagle Ford after the implementation of huff-n-puff, gas injection, specifically HnP, where a single well for injection and production is used, has become popular in tight reservoirs (Carlsen, M., Whitson, C., Dahouk, M. M., Younus, B., Yusra, I., Kerr, E., Mydland, S. 2019).

The research study is carried out to analyze the effectiveness of huff-n-puff gas unconventional EOR technique in tight oil reservoirs including the definition and current demand for unconventional deposits. HnP process is a single-well operation involving cyclic gas injection into a producer for a specific amount of time. The data is taken from one of the tight reservoirs of the USA, i.e., for confidentiality, the reservoir will be referred to as X in the paper. Compositional numerical simulation is built in Sensor of Coats Engineering. The single fracture dual porosity model is used for case runs without diffusion. The swell tests are carried out in PhazeComp, PVT software to analyze the miscibility phenomenon.

The study shows that additional oil, up to 10% of original STOIP, can be recovered with HnP EOR technique in tight reservoirs, which provides optimistic perspective for HnP EOR. The methodology does not include the diffusion process, which needs to be analyzed in the continuous future work.

The Influence of Various Factors on the Dynamics of Well Flow Rates in the Deposits of the Bazhenov Formation

Egorov Denis Sergeevich*
Graduate student, Gubkin Russian State University of Oil and Gas, Russia
*Corresponding author: eds.denis@yandex.ru

Keywords: unconventional resources; Bazhenov formation; hydraulic fracturing of horizontal wells; well production decline rate.

In recent years, the reserves of developed traditional hydrocarbon fields have been depleted. The development of unconventional and hard-to-recover oil and gas reserves of low- and ultra-low-permeability formations is becoming topical.

The purpose of the study is to assess the impact of geological and technological parameters on the efficiency of the development of low-permeability heterogeneous reservoirs of the Bazhenov formation and analogues.

The objects of study are the productive deposits of the Bazhenov and Achimov formations of Western Siberia in Russia. An analysis and comparison of pilot development of hydrocarbons in unconventional reservoirs of the Bazhenov formation (and their analogues) using multi-stage hydraulic fracturing in horizontal and directional wells is carried out. Study of the influence of geological and technological factors on well flow rates.

Based on the data of pilot well development, the dynamics of technological indicators are interpreted and characteristic areas of well operation are identified. Found and presented a comparison of the coefficients of the rate of decline in well production. Studies have been carried out to identify the dependences of the rate of decline in well production rate on geological factors, well design and parameters of the applied development technologies, in particular, hydraulic fracturing.

Thus, in further studies, the results can be used in determining the criteria for the effectiveness of applied technologies and development directions, as well as to get a more accurate understanding of the processes in the reservoir and find optimal solutions for the development of unconventional, low-permeability oil and gas fields.

ThEOR BAKU

Experimental Study on the Kinetic Characteristics of Heat Injected CO_2 Pyrolysis of Shale Oil with Medium and Low Maturity and and Evaluation of Kerogen Conversion Efficiency

Pu Wanfen [a b], Jin Xing [a*] , Pu Jun [c], Bai Yuanyuan [a], Wu Tong [a], Wang Aoyu [a]

[a] State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, Sichuan 610500, China

[b] Tianfu Yongxing Laboratory, Chengdu 611130, China

[c] Sinopec Petroleum Exploration and Production Research Institute, beijing 100083, China

[*] Corresponding author: 849600559@qq.com

Keywords: Medium and Low Maturity Shale Oil; SC-CO_2; Kinetic Characteristics; Kerogen Conversion Efficiency

Thermal development is the main means of medium and low maturity shale oil. The in-situ injection of high-temperature supercritical CO_2 produced from coal to hydrogen into shale oil reservoir provides basic conditions for the conversion and development of medium and low maturity shale oil.The purpose of this paper is to study the pyrolysis kinetic parameters of medium and low maturity shale oil injected with high temperature CO2, and the influence of CO_2 at different temperatures on the pyrolysis parameters of medium and low maturity shale oil. The samples in this paper are taken from Chang 7 Formation in Yanchang, Ordos Basin. First, the geochemical parameters of the samples are obtained through TOC, Ro, XRD and rock pyrolysis, and the kerogen type is determined to be II1. Samples with high, medium and low TOC were selected to conduct pyrolysis experiments of shale oil in open system at different heating rates under CO_2 atmosphere on TG-DSC instrument, and activation energy parameters were calculated based on the F-W-O integral method and Friedman differential method of Arrhenius theory. The kinetic parameters of shale oil pyrolysis in nitrogen atmosphere were used as a control experiment. Supercritical CO_2 immersion experiments at 100 ℃, 200 ℃, 300 ℃, 400 ℃ and 500 ℃ were carried out under the reservoir pressure of 20MPa. The gaseous products and solid products were tested by gas chromatograph and ROCK Eval VI respectively. The experimental results show that the activation energy distribution range of medium and low maturity shale oil in CO_2 environment is 218~365kJ/mol, which is greater than that in N_2 atmosphere. After CO_2 immersion at 400 ℃, the pyrolysis parameters S_0 and S_1 of the sample rock reach the maximum values of 0.9001mg/g and 13.4028mg/g respectively. At 500 ℃, it has dropped to 4.8664 mg/g, the initial parameter is 39.4060 mg/g, and the S_2 conversion rate is 87.6%. This study tested the pyrolysis kinetic parameters of medium low shale oil in CO_2 atmosphere, evaluated the conversion efficiency of supercritical CO_2 immersion at different temperatures for medium low maturity shale oil, and provided theoretical and experimental support for the development of heat injected CO_2 in such reservoirs.

Catalytic improvement of the in-situ Combustion process by transition metal Perovskites

Lucia Akimushkina[a,b *], Mikhail A. Varfolomeev[a,b*] Chendong Yuan [a,b]
[a] Institute of Chemistry, Department of Physical Chemistry, Kazan Federal University,420008, Russia
[b]Institute of Geology and Petroleum Technologies, Kazan Federal University, Russia
*Corresponding authors: akimushkina@gmail.com, vma.ksu@gmail.com

Keywords: In-situ combustion, Perovskite, Catalyst, kinetics, heavy oil.

In-situ combustion (ISC) is a high potential thermal enhanced oil recovery (EOR) method for heavy oils. However, the establishment and maintenance of combustion front is a challenge because it depends on combustion reactions velocity which restricts front generation and maintenance in some cases. This work presents an evaluation of perovskites as catalysts to assist a in situ combustion process of a heavy crude oil. The effect of these catalysts was investigated by kinetic calculation.

Perovskites of transition metals were prepared with different combinations and proportions. In total, five perovskites were tested with compositions of $Ce_{0.85}Mn_{0.15}O_2$, $LaNi_{0.6}Co_{0.4}O_3$, $LaMn_{0.5}Fe_{0.5}O_3$, $LaMnO_3$ and $LaCoO_3$. Its effect over heavy oil oxidation was evaluated by means of a reactor packed with oil, non-reactive sand, and the corresponding perovskite. Constant air flow was provided meanwhile a heating rate was applied. Three heating rates where used (2,3,5 C/min) to obtain apparent Kinetic parameters by isoconversional integral method.

Activation energies as function of temperature were obtained for each one of the perovskites. It is observed an effect associated to the catalyst addition. All the perovskites improved the reactivity of the systems in at least one of the two main regimes of reaction, Low temperature oxidation (LTO) or high temperature oxidation (HTO), compared with the system without catalyst. The best performance was presented by $LaNi_{0.6}Co_{0.4}O_3$ which decreased activation energy from 80 KJ/mol to 65 KJ/mol in LTO reactions and from 90 KJ/mol to 83 KJ/mol in HTO reactions. The systems reactivity improvement by perovskite indicates that are promising materials to assist the formation and maintenance of the combustion front of an in-situ combustion process of heavy and extra heavy oils.

Experimental study on the air injection for enhanced oil recovery in Jimsar shale oil reservoirs in China

Wenxuan GUO[a*], Jie Li[a], Hongjuan YOU[a], Jianghe SUN[a], Sen CHEN[a], Rigu SU[a] Dengya CHEN[a] Xiandong XIAO[b]

[a] Research Institute of Engineering Technology, PetroChina Xinjiang Oilfield Company, Karamay 834000, P. R. China.

[b]Fengcheng Oilfield Operation Area, PetroChina Xinjiang Oilfield Company, Karamay 834000, P. R. China.

[*] Corresponding author: guowx96@foxmail.com

Keywords: Shale oil ; EOR ; Air injection ; Combustion front propagation ; High-temperature combustion

Abstract: Shale oil has become an important resource for alternative development. The Jimsar shale oil reservoirs located in China is characterized by rapid production decline, low recovery, and lack of effective enhanced oil recovery methods after fracturing. Air injection has received considerable attention in the area of the development of shale oil reservoirs owing to its advantages such as in-situ upgrading, oxidative thermal cracking, high oil recovery, and low cost. To further study the feasibility of air injection for enhanced oil recovery in shale oil reservoirs, a total of six experiments with different ignition temperatures and initial water saturation were carried out by using the one-dimensional combustion tube. The performance and the combustion front propagation of air injection were analyzed combined with the data of temperature profile, effluent gas compositions, and liquid production. Additionally, the temperature and combustion zone distribution characteristics of air injection for shale oil and heavy oil were studied comparatively. Results show that Jimsar shale oil exhibits a high oxidation activity, and can achieve stable high-temperature combustion with final oil displacement efficiency is 64.3%. There is no obvious coke zone in the air injection process, different from the combustion of heavy oil fire flooding. Besides, the stability of the combustion process is sensitive to ignition temperature, water saturation, and air injection rates. The findings of this study reveal the high-temperature oxidation properties of shale oil, which have guiding significance for the efficient development of shale oil reservoirs.

EOR FIELD APPLICATIONS (INCLUDING FLUE GAS EOR)

Increase oil recovery in different surfactant concentration on the basis of increasing well drainage area as a result of increase in displacement efficiency

Jabrayil Eyvazov[a] *, Urfan Guliyev[b], Elchin Suleymanzade[c]
[a]Oil and Gas Scientific Research and Design Institute, 88a Hasan bey Zardabi Avenue, Baku
[b]Azerbaijan Technical University,25 Huseyn Javid Avenue, Baku
[c]Azerbaijan State Oil and Industry University,16/21 Azadliq Avenue, Baku
*Corresponding author: jabrayil.eyvazov88@gmail.com

Keywords: Enhanced oil recovery, surfactant flooding, waterflooding, interfacial tension, anionic surfactant, non-ionic surfactant

Surfactant flooding is an EOR technique in which surfactants and co-surfactants are injected into the reservoir to control the phase behaviour and create favourable conditions for the mobilization of stored oil.

In this study, Shallow Water Gunashli has been chosen for surfactant flooding. This method of EOR had done based on conventional water injection. The reservoir model was created for X horizon. There are 142 active producing wells from this horizon. Five spot water injection pattern is used in this case. All historical production, injection, pressure, perforation, and PVT data are included in the model. Firstly, history matching was done for the model. Three wells are selected for surfactant flooding purposes. They are Gun_042, Gun_081, and Gun_86. It was considered that, from July 2022, it was started to inject surfactant from these wells.

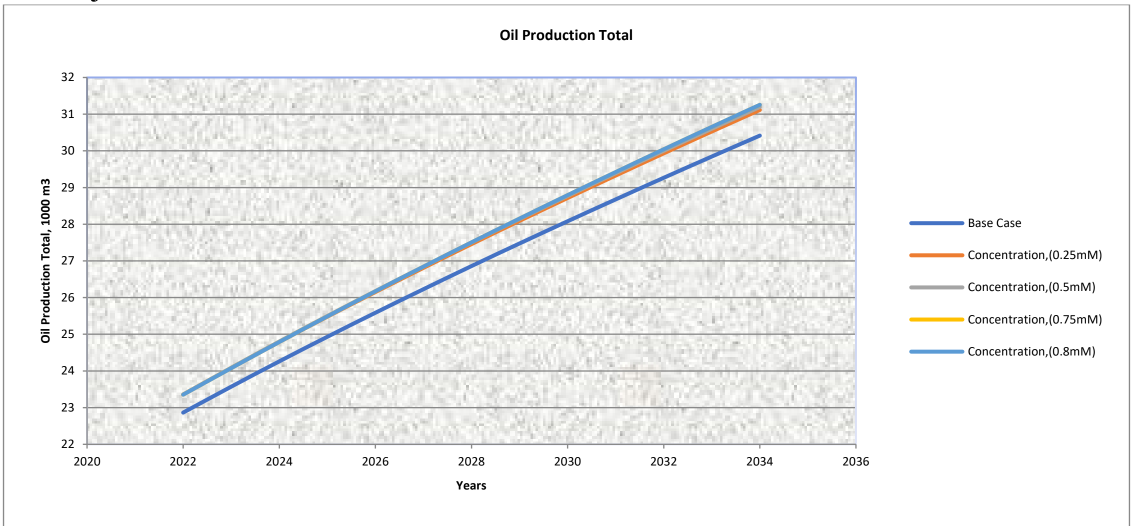


Figure 1. Oil production total in different concentration of surfactant flooding

The concentration of 0.75mM for surfactant flooding is the optimal concentration value under testing conditions because the recovery degree rose quickly and the water content fell quickly. The degree of recovery increases as the surfactant increases. Surfactant concentration is a key aspect in the effect of surfactant flooding. After 0.75 mM concentration, it doesn't effect to the oil production rate.

Therefore, 0.75 mM is considered optimum concentration for this case. Surfactant flooding reduce interfacial tension between the oil and water phases, also alters the wettability of the reservoir rock in order to mobilize the residual oil trapped in the reservoir, it improves volumetric sweep efficiency

Prospects of using thermal enhanced oil recovery methods in the Western (Qarbi) Absheron field

Mehdi A. Huseynov, Natig N. Hamidov, Dinara F. Huseynova, Jabrayil M. Eyvazov *.
Oil and Gas Scientific Research and Design Institute,SOCAR, Baku,Azerbaijan
*Corresponding author: jabrayil.eyvazov88@gmail.com

Keywords: Enhanced oil recovery, field development, hot water injection, highly viscous

One of the urgent issues is the application of modern approach methods, the selection of enhanced oil recovery methods on the reservoir for the correct organization of the field development, the extraction of a greater part of the oil and gas reserves, the maintenance of reservoir pressure and the increase of the final oil recovery coefficient.

Depending on the characteristics of the layer, the enhanced oil recovery methods are also different. For the successful application of each EOR method, the screening criteria of the method should be determined and the parameters given in those criteria should be compared with the reservoir parameters. As a result, from the existing methods of artificial influence on the reservoir, the appropriate EOR methods are selected according to the operational stage of the field, the existing technical conditions and the parameters of the reservoir.

In the presented study, the issue of choosing the enhanced oil recovery method on the Western Absheron field of Azerbaijan and predicting the results of these methods were considered.

The West Absheron field is currently in the first stage of development, operating mainly in the solution gas regime. A total of 86 wells have been drilled into the field, currently 59 wells are in operation. From the beginning of development, 1045.8 thousand tons of oil and 33.98 million m3 of solution gas were extracted from the field. The deposit is lithologically very heterogeneous, and the oil that saturates it is highly viscous.Therefore, additional screening and comparative analysis was carried out in order to select an effective enhanced oil recovery method. Extensive research was conducted to justify the selection of an effective enhanced oil recovery method to the reservoir based on the laboratory study of the physico-chemical and thermodynamic properties of the fluid samples taken from the horizons of the deposit, as well as the analysis of the lithological composition of the rock samples. As a result of the conducted studies, it has been proven that the injection of hot water into the layers of the Western Absheron field is more efficient.

In order to predetermine the results of the selected EOR method, the hot water injection process was modeled, and the obtained results were compared with other EOR methods.

In order to model the EOR method, a complete geological model was built on the basis of structural, lithofacies and petrophysical models of the productive horizons of the deposit based on geological-mining data, and a reservoir model was built on the basis of this model. On the basis of the established model, the performance indicators of the field were predicted by implementing both the base case and the EOR method.

At the same time, the production results of wells to be drilled into the field were predicted, and the changes of the EOR method parameters to the layout of these wells were taken into account.

APPLICATION OF ARTIFICIAL INTELLIGENCE TOOLS IN THE OIL RECOVERY

Prediction of Multiphase Flow Rate for Reservoir Modeling Using Deep Neural Networks

Asad Safarov
Azerbaijan State Oil and Industry University, Azerbaijan
Corresponding author: eseferov0@gmail.com

Keywords: artificial intelligence; big data; rate prediction; deep learning, reservoir management.

Artificial intelligence, or simply AI, is a type of intelligence exhibited by machines, as opposed to the inherent intelligence demonstrated by animals and humans. AI studies have been characterized as the study of intelligent agents, which means any systems that sense its surroundings and take decisions to optimize its chances of success. Deep learning is a type of Artificial Intelligence that involves numerous layers to extract higher-level characteristics from raw input. In image processing, for example, lower layers may recognize boundaries, while higher layers may identify concepts meaningful to humans, such as digits, characters, or faces. Another example is to predict a value of any tendency using big data which is called a supervised regression analysis.

In recent years, the application of different artificial algorithms is an increasing trend in the petroleum industry. It ranges from geoseismic data interpretation to reservoir management. In this paper, the application of deep neural networks is introduced to predict a production rate for multiphase flow. For this, the various parameters are required as input data such as geological data, reservoir fluid parameters, completion data and well geometry. To improve the accuracy of the deep learning analysis, it is recommended to use more data samples. We can increase the number of data simply using simulated data or real field data. The results show that deep neural networks have a high accuracy to predict a rate of fluid flow.

ThEOR BAKU

Using Deep Learning for Waterflooding Optimization in Condition of High Geological Uncertainty and Reservoir Heterogeneity

Ramil Guliev*
Northern (Arctic) Federal University named after M.V. Lomonosov, Russia
* Corresponding author: r.guliev@narfu.ru

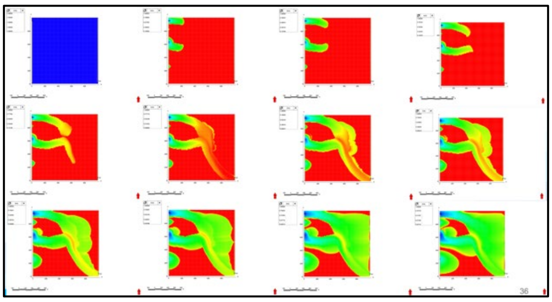
Keywords: waterflooding; displacement of hydrocarbons; machine learning; deep learning; data assimilation; reservoir simulation

This work shows the results of developing and implemetation a deep learning algorithm (DL) – generative-adversarial network (GAN) and demostrares the process of creating a system with the integration of permeability data, as well as the process of decreasing the uncertainty of permeability properties using GAN-ensemble smoothing and using DL for optimization of waterflooding process in condition of high geological uncertainty and reservoir heterogeneity.

In the first part of the work, the process of parametrization of reservoir properties using a deep learning algorithm demonstrates. A generative adversarial network is used to generate reservoir properties, where the generator (G) and discriminator (D) are designed as convolutional neural networks (CNN), using the efficiency of the CNN's image feature detection capabilities. The training image is a synthetic reservoir section with permeability anisotropy. The result of the experiment showed reservoir recovery with a certain propagation probability.

The second part of the work shows a deep learning network architecture including a pair of autoencoder that cover continuous data detection for non-linear inverse mapping between data and model. The results of the study show that with incomplete data under conditions of permeability uncertainty, the algorithm is capable of parameterizing reservoir properties and reducing uncertainty.

Once an appropriate model has been created, it can be used in real time to simulate and optimize fluid flow or waterflloding process. As an applied significance of the results of the study, the solution of the problem of optimization of waterflooding process of an oil reservoir using reservoir simulation under condition of heterogeneity and uncertainty of the geological properties is shown. Based on the results of reservoir simulation, the technological effect of increasing of cumulative oil production, reducing cumulative water production and increasing the oil recovery factor was determined (Fig. 1).



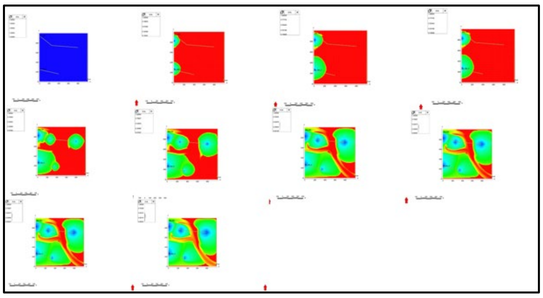


Figure 1 – Waterflooding Efficiency: left – without usind DL algorithm and waterflooding optimization, right – using DL algorithm and waterflooding optimization; green color means water saturation, red – oil saturation

Decision making on the classification of oil reservoirs with respect to effectiveness using fuzzy pareto optimality formalism

L.A.Gardashova *
Azerbaijan State Oil and Industry University, Azadliq Ave.34 , Baku, Azerbaijan
* Corresponding author: qardashova@asoiu.edu.az

Keywords: reservoir, well, formation water, gas-oil-water mixture, water production, water-oil factor, profit/loss investigation, economic efficiency, Pareto optimality, fuzzy optimality, sensitivity.

Analysis of the ill-defined problems of decision-making is one of topical issues in the applied decision theory. We applied fuzzy Pareto optimality (FPO) formalism to solve fuzzy multiobjective optimal control problem. For such problems, application of the well-known existing approaches would be complex both form intuitive and computational points of view. Application of FPO formalism allowed obtaining intuitively meaningful solution for the considered problem complicated by three criteria and non-stochastic uncertainty intrinsic to real-world economic problems. This is due to the fact that FPO formalism develops Pareto optimality principle by differentiating between “less” and “more” Pareto optimal solutions. We obtained five fuzzy Pareto optimal solutions with different degrees of optimality. The degrees of optimality are intuitive description of optimality and provide a freedom for choosing an appropriate solution (control actions) when the solution with the highest degree of optimality may not be implementable in a real-world situation. The results obtained in the paper show validity of the applied approach.

The approach allows us to draw the following conclusions:

- organize periodic operation of highly watered reservoirs and wells;
- implement measures to restrict the flow of water into the well;
- the application of forced fluid withdrawal has carefully to be weighed.

By regulating the amount of water withdrawn from the reservoir and wells, taking into account the profitability of oil production, can be controlled economically efficiency development of formation and operation of the well.

GEOLOGICAL PROBLEMS OF ENHANCED OIL RECOVERY

The effect of dislocation with a break in continuity on the productivity of high-carbon low-pore clay-carbonate strata

Prishchepa Oleg Mikhailovich, Nefedov Yuri Viktorovich*, Gribanov Mikhail Aleksandrovich
Department of Geology of Oil and Gas, Saint-Petersburg Mining University, 22 line, 2, 199106 St. Petersburg
* Corresponding author: Nefedov_YuV@pers.spmi.ru

Keywords: unconventional high-carbon formations; domanik; bazhen; dislocation with a break in continuity; productivity.

The pace of exploration of high-bituminous strata that widely developed in the Russian Federation, which have a huge hydrocarbon potential and are characterized by extremely low reservoir porosity and permeability, is very uncertain. The total potential of such (Bazhen, Domanik, Khadum, Kuonam) strata of the "old" oil-producing regions is estimated from 10 to 75 billion tons of technically recoverable oil reserves.

The predominantly clay composition and the absence of a rigid framework make it possible to effectively apply horizontal drilling technologies and multistage hydraulic fracturing during development, which is used with a significantly carbonate composition of the conjugated sites (for example, organogenic structures in Domanik deposits in the VUOGP (Volga-Urals Oil and Gas Province) and TPP (Timan-Pechora Province).

At the same time, numerous studies and tests of wells in predominantly clay strata that aimed at obtaining industrial oil inflows indicate the positive role of both natural fracturing and faults in increasing flow rates and their non-catastrophic reduction in a short time.

In the study of assessing the productivity of wells that have uncovered low-permeable high-carbon strata in the territories of WSOGP (West Siberian Oil and Gas Province), TPP and VUOGP, the influence of faults on the formation of zones of improved reservoir porosity and permeability and zones of accumulation of hydrocarbons due to migration processes (primary and secondary), including the assessment of the introduction of micro oil from outside the strata, is estimated.

The most significant is the conclusion about the contribution of faults to the formation of additional channels of natural permeability. Also, the possibility of localization of such zones using seismic methods of study, and their influence on the hydrocarbons redistribution due to secondary migration and epigenetic processes leading to the formation of unlimited in area (in size) accumulations of hydrocarbons, which are the subject of future research. It is worth noting the ambiguous effect of faults on the wells productivity in carbonate reservoirs, which is explained by the same epigenetic changes that lead to the "healing" of previously formed fractures.

The search for criteria for zoning of increased productivity and the development of technologies for the hydrocarbons extraction of low-pore and low-permeable clay-carbonate strata, that based on the assessment of the influence of deep fault tectonics, it will allow us to consider high-carbon strata as the nearest reserve for oil production in industrially developed areas.

COMBINED METHODS FOR STIMULATION OF THE FORMATION

Innovative Solutions for Progressive Cavity Pumping Units

Anatoliy Andreevich Isaev *
Sheshmaoil Management Company LLC, Russian Federation
*Corresponding author: isaeff-oil@yandex.ru

Abstract. The screw segments (sucker rod vanes) on a sucker rod string is one of the technical solutions developed by Sheshmaoil LLC specially for PCP units that can be used to increase their head and facilitate the operation of screw pumps and a sucker rod string (fig.1). The article provides the outcomes of sucker rod vanes' implementation in wells, bench tests (fig.2) and scientific substantiation of sucker rod vanes' application, i.e. theoretical estimation of the head generated by sucker rod vanes, an empirical formula and table of empirical coefficients for each type of vanes were obtained. The basic guidelines for selecting vanes for wells are proposed.

A centralizer has been developed to provide the necessary coaxial alignment of a string of sucker rods to the tubing (fig.3). Thanks to this type of centralizers, it becomes possible to operate horizontal and strongly deviated wells, thereby increasing the productivity or gaining access to hard-to-reach pay zones. Using centralizers as a part of a rod string will help reduce dangerous resonant oscillations and increase the operating time of PCP units.

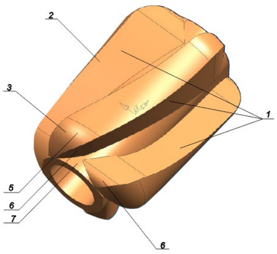


Fig.1.

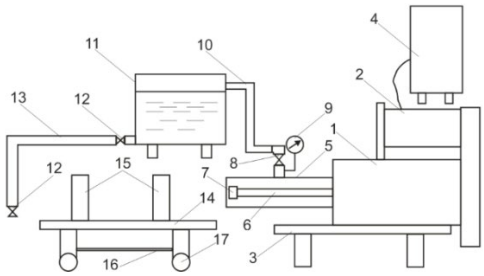


Fig.2.

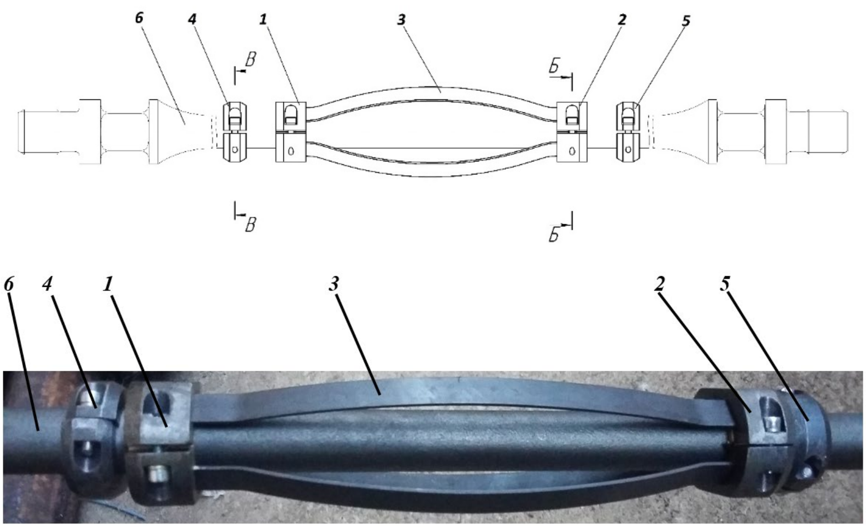


Fig.3.

Comparative study of models for gas hydrate formation temperature prediction

Victor L Malyshev, Elena F Moiseeva*
Ufa State Petroleum Technological University, Russia
*Corresponding author: elena.f.moiseeva@gmail.com

Keywords: natural gas, hydrates, temperature of hydrate formation, equation of state.

Determining the conditions for hydrate formation is one of the key tasks in the production, transportation and processing of natural gas. The formation of gas hydrates can lead to blockage of the well space, pipelines, equipment malfunctions and a decrease in wellhead pressure, which negatively affects technological processes and associated with additional costs. In the last decade, studies of gas hydrates have been devoted not only to preventing their formation, but also to finding the most effective methods to use hydrates for gas storage and transport. However, the low hydrate formation rate, as well as the thermobaric conditions of their existence (low temperatures and high pressures) impose serious restrictions on the development of technologies and equipment for solving such problems. The choice of optimal methods for determining the conditions of hydrate formation can significantly improve the accuracy of predicting this process, as well as improve technologies for both hydrate control and their intended use. Therefore industry requires simple predictive models for phase diagram understanding and process design. The paper considers the main correlations used to determine the conditions for hydrate formation for gases of various densities. The influence of the choice of the correlation function on the accuracy of determining the temperature of hydrate formation has been studied. It is shown that the correlation proposed by Ponomarev G.V. allows to obtain the highest accuracy in determining this parameter. The other correlations considered (Mottie, Berge, Bahadori, Towel and Hammerschmidt) have significant limits on the range of applicability. When gas composition is known, the temperature of hydrate formation is determined from phase diagrams based on the equations of state. The most accurate results are shown by the advanced Redlich-Kwong-Soave model with an explicit association term implemented in Multiflash software, especially in cases where the gas contains heavy hydrocarbon or non-hydrocarbon components. In addition, the influence of non-hydrocarbon components mole fraction on the temperature of hydrate formation are studied in the work. It is shown that an increase in the content of hydrogen sulfide leads to an increase in the equilibrium temperature of hydrate formation, while gases with a high content of nitrogen and carbon dioxide are characterized by lower temperatures of hydrate formation.

Using Low Salinity Water for EOR

Elnur Alizade*
Azerbaijan State Oil and Industry University, Azerbaijan
*Corresponding author: e.alizade.99@gmail.com

Keywords: water flooding; saline water; salt; production; injection; simulation; reservoir; oil; saturation; permeability; porosity; oil recovery; formation; fluid.

The water flooding technique is one of the most widely used and efficient technique for increasing oil recovery. In an oil-wet reservoir, however, the higher the water mobility, the lower the oil production. The following research will look into the effects of high and low saline water floods on oil recovery and water mobility. This research also looks at how varied water salinity injections affect wettability and salt production rates. The design of a three-dimensional, two-phase model, i.e., water and oil, is the first step in this research. Initially, the reservoir is oil-wet. To show the wettability change, relative permeability curves are generated during simulation. The impact of salinity on oil production, water mobility, and salt production is examined by a comparison of high and low saline water floods. In order to identify an effective well injection technique, a sensitivity analysis was done for two possible injections well patterns: five spot and direct line drive. The recovery attained by lowering the salinity of the water was found to be around 80%, with a cumulative oil production of 0.45 MMSTB. The water cut is prolonged to a large extent by lowering the salinity of the water. Furthermore, salt content was reduced at the production well. Thus, in the case of an oil wet reservoir, lowering the injection water salinity proved to be an appropriate and effective strategy for increasing oil recovery.

MODELING OF HEAT AND MASS TRANSFER PROCESSES IN PETROLEUM INDUSTRY

Pressure Waves in a Tube Containing Liquid With Bubble Cluster

Uliana O. Agisheva [a*], Marat N. Galimzyanov [a, b]
[a] Mavlyutov Institute of Mechanics. Ufa Investigation Center, R.A.S., Russia
[b] Bashkir State University, Faculty of Mathematics and Information Technology, Department of Mathematical Modeling, Russia
[*]Corresponding author: agisheva_u@mail.ru

Keywords: cylindrical channel, bubble cluster, bubble liquid, pressure wave, spherical and toroidal bubble cluster

The considerable interest of researchers in the problems of the mechanics of bubble media is due to the wide distribution of such systems in nature and their intensive use in modern technology. In this case, the most interesting and important are the processes that are non-stationary in nature. Bubble liquids are liquids with special properties. With small additions of bubbles the medium becomes highly compressible while maintaining a density close to that of a liquid which leads to a nonlinearity of the medium. In addition bubble media mainly due to the manifestation of interfacial heat transfer have strong dissipative properties. The combined interaction of nonlinear, dissipative, and dispersion effects leads to significant features of the propagation of perturbations in bubble media.

In this paper we study two-dimensional axisymmetric wave perturbations in a channel with water containing a spherical cluster filled with a water-air bubble mixture. To describe the wave motion taking general assumptions for bubbly liquids a system of macroscopic equations for the masses, the number of bubbles, momenta, and pressure in the bubbles is written in the approximation of cylindrical symmetry. The system of equations was solved using an explicit scheme. A uniform chess grid was used for calculations. Based on the results of numerical calculations, the dependence of the maximum pressure amplitude formed in the channel on the geometrical parameters of the cluster and channel as well as on the amplitude of the initial impact was analyzed.

It has been established that the interaction of a "step" wave with a spherical bubble cluster in a liquid leads to the generation of a solitary pressure wave with an amplitude much greater than the shock wave amplitude. A decrease in the bubble radius and gas volume content leads to an increase in the amplitude of the solitary wave due to an increase in the acoustic rigidity of the bubble cluster. In the case of a spherical cluster adjacent to the channel end surface, the impact on the end wall with the highest wave amplitude occurs in the case of a cluster with a radius equal to half the channel radius. Clusters with radii of a quarter and three quarters of the channel radius have the same result in terms of the amplitude of the signal incident on a solid wall, but at different times. This is due to the geometry of the problem and the difference in wave velocities in the liquid and inside the cluster.

It has been established that in the case of a cylindrical cluster the amplitude of the wave signal behind the bubble zone is several times higher than the amplitude for the case of a cylindrical toroidal cluster. Numerical studies have shown that the focusing of the signal behind the bubble region occurs earlier for a solid cylinder than for a toroidal one. This work was supported by the government budget for the state task for 2019–2023 years (project FWGZ-2019-0052).

Optimization of thermal and chemical development methods using high-viscosity oil reservoir model obtained as a result of history matching

Marina G Persova[a], Aleksandr A. Dyakonov[b], Arslan V. Nasybullin[b], Yury G. Soloveychik[a], Evgenii V. Orekhov[b], Azat A. Lutfullin[c], Anastasia S. [a]. Ovchinnikova[a], Daryana A. Leonovich[a]
[a]Department of Applied Mathematics, Novosibirsk State Technical University, Novosibirsk, Russia
[b]Department of development and exploitation of oil and gas fields, Almetyevsk State Oil Institute, Almetyevsk, Russia
[c]TATNEFT, Almetyevsk, Russia

Keywords: thermo-hydrodynamic model, history matching, forecasting, optimization

The paper is devoted to the study of the possibilities of thermal and chemical methods for the development of high-viscosity oil fields using software that implements 3D modeling of a non-isothermal multiphase flow in a porous medium, automatic history matching for obtain the reservoir model, as well as analysis of various development scenarios based on optimization of well operation modes, taking into account the properties and composition of injected agents.

We use the program of thermo-fluid dynamic modeling and solving inverse problems of fluid- and thermodynamics. The program makes it possible to conveniently set the principles of the interaction of phases and their components in the reservoir, which allows simulating various mechanisms for the interaction of injected agents with the matrix-rock and fluid. The program includes modules for history matching and synthesis of optimal control of the impact on the reservoir. Algorithms for constructing the optimal plan are based on 3D modeling of non-isothermal multiphase flow and minimization of the objective function, which includes the main development indicators and regularizing additives that ensure the fulfillment of technological restrictions.

The traditional approach to field development optimization consists in manual adjustment of production modes and selection of injected agents and their properties. This requires a large number of calculations, depends on the human factor and does not guarantee the optimality of the resulting solution. The industry has software that allows you to automate this process to some extent, for example, Enable, MEPO. However, the search time for the optimal solution is extremely long and does not allow for efficient management of the field development. Our algorithms provide fast finding the optimal solution, allowing us to explore various development scenarios using enhanced oil recovery methods. The quality of the solutions obtained is ensured by the high adequacy of the history-matched reservoir models which are used in the procedures for optimizing oil production.

For the history-matched reservoir models, various development scenarios with the injection of cold and hot water, as well as with the injection of a surfactant-polymer composition, were investigated using optimization procedures. The possibility of improving production performance through the use of optimization procedures is shown.

Local Thermal Equilibrium Constraints for Energy Transport Equations for Thermal Oil Recovery Processes

Daniel Fuentes-Ibarra[a], Octavio Cazarez-Candia[a,*], Carlos G. Aguilar-Madera[b]
[a]Instituto Mexicano del Petróleo, México
[b]Universidad Autónoma de Nuevo León, México
[*]Corresponding author: ocazarez@imp.mx

Keywords: Thermal enhanced oil recovery; energy models constraints; local thermal equilibrium; reservoir simulation.

Reservoir thermal simulators conventionally assume local thermal equilibrium (LTE) to predict the energy transport through porous media for petroleum engineering applications such as Thermal Enhanced Oil Recovery (TEOR) processes. This assumption implies instantaneous energy transport between the hot fluids injected and the reservoir rock and fluids. The LTE has been considered a valid approximation for the energy transport mechanisms presented in the reservoir, nevertheless, there are certain conditions under which the LTE is not valid and may lead to an overestimation of the oil recovery, e.g., when high fluid velocities arise. At those conditions, the local thermal non-equilibrium (LTNE) might accurately represent the energy transport's physics. In this work, we derived the mathematical constraints for the usage of LTE (one-equation model for the fluids and rock) and pseudo-LTNE (two-equation model, one for the fluids and one for the rock), via the method of volume averaging applied on an oil-water-gas-rock system at the pore-scale. Such constraints were derived in terms of conductive and convective heat transport properties. To evaluate the validity of the energy equations proposed, the thermal conductivity tensors of both models were estimated for different pore-scale distributions and compared to each other (Figure 1), according to the derivation theory implementation. It is noteworthy that the horizontal conductivity is much higher than the vertical as the Peclet increases, because of a horizontal pressure drop imposed across a pore-scale system. The equations presented in this work showed consistency and aid in evaluating the reliability of using an energy transport model for specific TEOR mechanism scenarios.

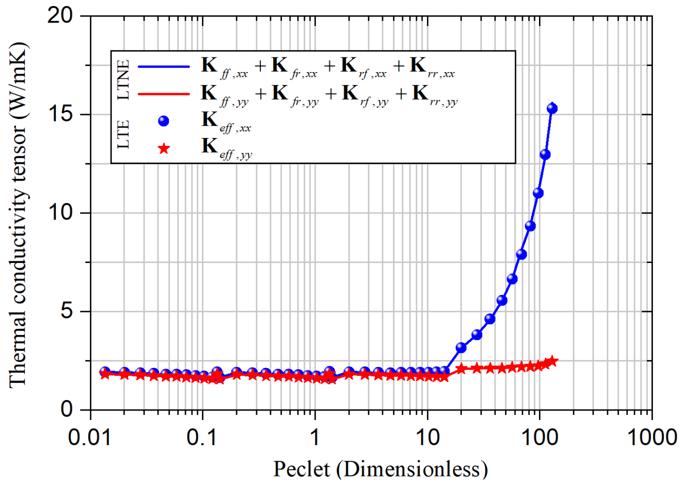


Figure 1. Thermal conductivities for the one-equation (LTE) and two-equation models (LTE).

Features of Determination of Relative Phase Permeabilities in the Oil-Hot Water (Steam) System for the Heavy Oil Carbonate Reservoir

Pavel Grishin[a*], Tagir Karamov[a], Evgeny Popov[a], Gennadiy Usachev[b], Natalya Lesina[b], Alexey Cheremisin[a]

[a] Skolkovo Institute of Science and Technology (Skoltech), Russia

[b] LTD «LUKOIL ENGINEERING», Russia

[*] Corresponding author: p.grishin@skoltech.ru

Keywords: thermal EOR, relative phase permeabilities, carbonate reservoir, heavy high-viscosity oil.

When conducting single-phase or multi-phase hot water / steamflood experiments with heavy, high-viscosity oil on carbonate core samples in order to determine oil displacement coefficients, stationary or non-stationary relative phase permeabilities, various problems may arise that may lead either to significant errors in measured parameters, or even to the impossibility to conduct the experiment. The situation is complicated by the fact that these problems are caused by various physico-chemical processes.

So objectives of this study are: to establish the causes of problems during coreflood experiments; rank them according to their significance and conditions of occurrence; determine their nature and ways to control or eliminate them (if possible).

To solve these tasks, a series of experiments under temperatures from 26 C to 345 C and reservoir pressure were carried out using an autoclave and a high-temperature coreflood unit (on the base of ramped temperature oxidation reactor) and a deep analysis of samples using auxiliary analytical equipment, including: an X-ray tomograph, scanning electron microscope, rheometer, etc.

Laboratory studies and subsequent analysis showed that the decrease in the absolute and relative permeabilities of the carbonate rock under thermal treatment consists of two components: irreversible and partially reversible (associated mainly with the adsorption of high molecular weight hydrocarbon components). Three key pore space processes/effects responsible for irreversible permeability decrease were determined: mechanical - partial or complete destruction of the microcrystalline calcite rim of the pores; physical and chemical - the formation and partial migration of needle-like crystals of wollastonite ($CaSiO_3$) in the pore space with increasing temperature; chemical - local formation of organic oil wet films on the reservoir mineral surface. The appearance of these processes and their contribution to the resulting effect depend on the fluid temperature and, to some extent, on the phase flow composition.

As the result of the studies, the hypotheses of the permeability decrease were confirmed, but for the formation of a universal, replicable methodology of the relative phase permeabilities determination for thermal treatment of heavy oil carbonate reservoirs more statistics and further verification at other objects is required.

Identification of Elastic Boundary Conditions and Crack Depth

Torgyn M. Mannapova [a,*], Marat N. Galimzyanov [a, b]
[a] Bashkir State University, Faculty of Mathematics and Information Technology, Department of Mathematical Modeling, Russia
[b] Mavlyutov Institute of Mechanics. Ufa Investigation Center, R.A.S., Russia
[*] Corresponding author: mannapovatm@mail.ru

Keywords: boundary inverse problem, conjugation conditions, boundary conditions, identification of boundary and conjugation conditions

The purpose of this work is to establish the possibility of determining the stiffness of springs of elastic fastening at both ends of the rod, as well as the depth of the crack between the ends of the rod by four natural frequencies of longitudinal vibrations of the rod.

For the solution, methods were used to identify the boundary conditions for which all coefficients are unknown. The boundary conditions identification method was used based on a simplified model.

It has been established that if the crack is located in the middle of the rod, then the stiffness of the springs is determined up to a change in the places of fastening by places of the stiffness coefficients of the springs at its ends, and the depth of the crack is determined uniquely. If the crack is not located in the middle of the rod, then the stiffness of the springs, as well as the depth of the crack, are uniquely determined.

It can be concluded that the type and parameters of the fastening of the rod, as well as the conditions for pairing the rod, expressing the presence of a spring or a crack between the ends of the rod, can be determined by four natural frequencies.

This work was supported by the government budget for the state task for 2019–2023 years (project FWGZ-2019-0052)

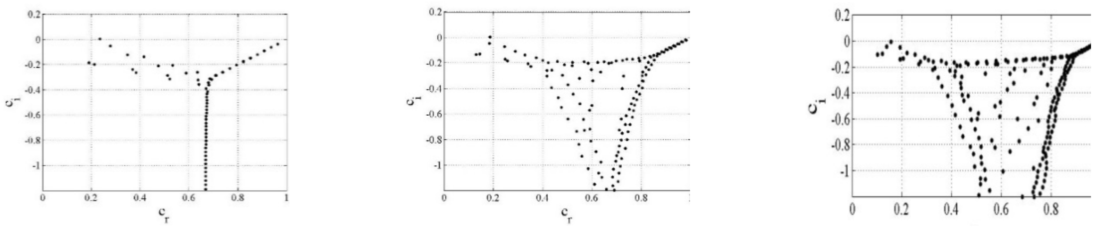
The eigenvalues spectra analysis of the flow instability equation for a thermoviscous liquid in an annular channel

Adelina D. Nizamova [a*], Viktor N. Kireev [b], Said F. Urmancheev [a]
[a] Laboratory of Multiphase Systems Mechanics, Mavlyutov Institute of Mechanics, Russia
[b] Applied Physics Department, Bashkir State University, Russia
[*] Corresponding author: adeshka@yandex.ru

Keywords: thermoviscous liquids; eigenvalues spectra; hydrodynamic instability; annular channel; Orr-Sommerfeld equation ; Chebyshev polynomials

The critical conditions of laminar-turbulent transition, that is obtained from solution of the linear theory of hydrodynamic stability equations, can only be considered as estimates. Nevertheless, these estimates serve as an important reference point in the design of hydraulic equipment in oil industry. The classical formulation of the hydrodynamic stability problems suggests that the liquid viscosity remains constant. However, solution of the industrial application problems requires to take into account the real properties of liquids, which include the dependence of viscosity on temperature. This circumstance can be decisive in problems in which the liquid flow under intense heat exchange with the environment is considered.

In the present work, the stability problem for liquid flow in an annular channel taking into account the exponentially decreasing dependence of viscosity on temperature is stated. The choice of the annular channel is due to the sufficient generality of different solutions, which make it possible to obtain important limiting cases. The study of hydrodynamic stability was reduced to a spectral problem for the generalized Orr-Sommerfeld equation. To solve the eigenvalue problem the spectral method based on Chebyshev polynomials of the first kind expansion was applied. As a result of numerical solution, the eigenvalues spectra for different values of the thermoviscosity parameter α characterizing the degree of temperature dependence of viscosity and the geometrical parameter θ that equal to the larger radius of the annular channel to the smaller one (Figure 1).



a) b) c)

Figure 1. Eigenvalues spectra of generalized Orr-Sommerfeld equation:
a) $\alpha = 0,001$; $\theta = 1,001$; b) $\alpha = 2$; $\theta = 2$; c) $\alpha = 3$; $\theta = 4$.

The obtained results indicate the existence of a point with a positive imaginary part, which corresponds to an unstable flow regime, in those cases where the ratio of the radii is less than four. Otherwise, all the points will correspond to stable modes. An increase of the thermoviscosity parameter leads to a spread of eigenvalues in the lower branch of the spectrum, making it more rarefied and also it significant decreases the critical Reynolds number.

The study was supported by the Russian Science Foundation (Project No. 22-21-00915).

Numerical Modeling of the Blocking Effect of a Thermoreversible Polymer System in a Cylindrical Pipe Filled with Porous Media

Aygul A. Mukhutdinova [a], Victor N. Kireev [b], Said F. Urmancheev [a *]
[a] Laboratory of Multiphase Systems Mechanics, Mavlyutov Institute of Mechanics, Russia
[b] Applied Physics Department, Bashkir State University, Russia
[*] Corresponding author: said@anrb.ru

Keywords: thermoreversable systems; gelation; methylcellulose solution; blocking effect; numerical modeling;

The flow of a polymer liquid in a cylindrical pipe filled with porous layered media consisting of spherical particles of two different diameters is considered. The inner part of the pipe is filled with particles of smaller diameter, while the outer part of the pipe contains particles of larger diameter. Thus, the porosity of the medium in the inner part of the pipe is less than one in the outer annular region. The aim of this work is to study the regularities of the highly permeable region blocking process with a thermoreversible polymer composition when heat exchange with the environment occurs and to determine the optimal blocking parameters.

The mathematical model of the process consists of the system of differential equations written in cylindrical coordinates, which includes the continuity equation, the flow equations for an incompressible liquid with a temperature-dependent viscosity, and the equations of heat exchange. The interaction of a liquid with a immovable porous medium is described by introducing interfacial forces terms into the flow equations. The gelation kinetics of a thermoreversible composition is given by the dependence of viscosity on temperature. The mathematical model equations are solved numerically using the Finite Volume Method.

Previously, the authors studied in details the flow of some model liquid with a non-monotonic dependence of viscosity on temperature in a plane channel and found out the different fluid flow regimes depending on the dynamics of a high-viscosity zone. In the present work, the influence of heat transfer conditions between cylindrical layers of different porosity and the influence of thermal conductivity coefficients of bulk media on the hydrodynamic characteristics of the flow of a similar model fluid is considered.

In oil industry, an aqueous solution of methylcellulose with the addition of carbamide METKA is used as a thermoreversible composition. As a result of numerical studies, it was found that the nature of the flow of a thermoreversible composition, taking into account the possibility of gel formation with an increase in temperature and its subsequent destruction with a corresponding decrease in viscosity, will be fully determined by the high-viscosity gel zone and the conditions of heat exchange with the environment. The volumes of the inflowing solution for effective blocking of a highly permeable area and the conditions for the stability of the barrier are determined.

The study was supported by the Russian Science Foundation (Project No. 22-21-00915).

Effect of rheological properties of oil displacement agent on convective heat and mass transfer

Konstantin V Moiseev [a,b,*], Elena F Moiseeva [a], Ramil N Bakhtizin [a]
[a] Ufa State Petroleum Technological University, Russia
[b] Ufa Federal research center of the Russian academy of sciences, Mavlyutov Institute of Mechanics, Russia
[*] Corresponding author: constgo@mail.ru

Keywords: heat and mass transfer, convection, anomalous fluid, thermo-viscous fluid

The development of hard-to-recover oil reserves with low-permeability reservoirs, high water cut, high and abnormal viscosity of the fluid, requires improvement of existing and development of new methods of reservoir stimulation. For the effective development of such reserves, it is necessary to deeply study the physical and chemical methods of enhanced oil recovery using heat-and-mass transfer and oil displacement agent. The viscosity of aqueous solutions of methylcellulose, polyacrylamide, carboxymethylcellulose, due to the polymerization and depolymerization, decreases with increasing temperature to the gel point, and at after that it starts to increase. The formation of polymer chains, in a certain temperature range, in organic polymers leads to a significant increase in viscosity. An increase in temperature destroys these chains, which leads, respectively, to a decrease in viscosity. The temperature dependences of the viscosity of such compositions have a complex nonmonotonic character and can significantly affect the processes of heat and mass transfer and oil displacement. The numerical investigation of the convective heat and mass transfer of a fluid with a monotonic (exponential) and nonmonotonic (quadratic) dependence of viscosity on temperature is presented. The system of equations for convective heat and mass transfer in the Boussinesq approximation is solved by the control volume method. Verification of the computer program was carried out on the problem of benchmark solutions for natural convection. It is shown that for fluids with monotonic dependences of viscosity on temperature, the intensity of heat transfer does not depend on the sign of the first derivative of the viscosity function with respect to temperature and is determined by the relative viscosity, defined as the ratio of the integral of the square of the viscosity function to the integral of the viscosity function itself over a given temperature interval. The higher is the relative viscosity, the lower is the rate of heat transfer. For fluids with nonmonotonic viscosity dependences, it was found that the heat transfer rate depends on the relative viscosity (the higher is the relative viscosity, the lower is the heat transfer rate) and the sign of the second derivative of the viscosity function with respect to temperature. For fluids whose second derivative of the viscosity function takes negative values, the intensity of heat transfer turns out to be higher than for fluids whose second derivative of viscosity takes positive values (convex downwards).