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# МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

| **Тема работы** |
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| Изучение влияния гелеобразующих композиций на коэффициент нефтевытеснения |

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Оглавление

# Введение

В современном мире запасов тяжелых и высоковязких нефтей значительно больше, чем запасов легких и маловязких нефтей. Тяжелые и высоковязкие нефти являются важнейшей частью сырьевой базы нефтяной отрасли как в России, так и в ряде других нефтедобывающих стран мира. В связи с этим, разработке месторождений высоковязких нефтей уделяется все большее внимание.

В последнее время самыми распространенными методами увеличения нефтяной отдачи залежей нефти с высокой вязкостью становятся тепловые методы – вытеснение нефти с помощью пара, циклическое нагнетание пара в пласт и гравитационное дренирование при нагнетании пара. Такое воздействие на пласт применяется в основном в Канаде, США, Бразилии, Венесуэле, России и Китае. Из проектов увеличения нефтяной отдачи, выполненных в мире с применением тепловых методов за последние 40 лет 92 % проектов связаны с закачкой пара.

Сочетание паротеплового воздействия с физико-химическими методами, в частности, с применением термотропных гелеобразующих композиций, увеличивающих охват пласта закачкой пара, и нефтевытесняющих композиций, обеспечивающих дополнительное вытеснение нефти, увеличивают эффективность проводимых мероприятий по увеличению нефтяной отдачи. Комплексные методы, сочетающие паротепловое и физико-химическое воздействие на пласт, находятся в начальной стадии. Общая тенденция развития этих работ указывает на возрастание роли тепловых методов добычи, особенно в сочетании с физико-химическим воздействием.

Актуальность данной магистерской диссертации заключается в изучении влияния такого физико-химического метода увеличения нефтяной отдачи, как применение гелеобразующих композиций совместно с тепловым -пароциклической обработкой, на коэффициент нефтевытеснения.

Объектами исследования являются: модель высоковязкой нефти и пластовой воды пермокарбоновой залежи Усинского месторождения, дезинтегрированный керновый материал (модель карбонатного коллектора), гелеобразующие композиции №1 и №2®.

Цель работы заключалась в исследовании влияния гелеобразующих композиций на коэффициент вытеснения нефти пермо-карбоновой залежи Усинского месторождения в условиях, моделирующих пластовые.

Задачи, поставленные в процессе выполнения магистерской диссертации:

– Привести обзор методов увеличения нефтяной отдачи;

– Подготовить нефте-водонасыщенные модели неоднородного пласта пермокарбоновой залежи Усинского месторождения;

– Провести фильтрационные испытания модели неоднородного пласта, обработать и обсудить результаты, сделать выводы об эффективности применения гелеобразующих композиций ;

– Рассчитать предполагаемую экономическую эффективность от применения рассматриваемой технологии;

– Оценить возможные вредные и опасные факторы при выполнении исследований.

## Аннотация

В настоящее время тяжелые, высоковязкие нефти рассматриваются в качестве основного резерва мировой добычи нефти. Неуклонно прогрессирующие потребности мировой экономики в углеводородах будут удовлетворяться в основном за счет освоения новых нефтедобывающих регионов, преимущественно в полярных областях планеты, а также разработки месторождений тяжелых, высоковязких нефтей и битумов, запасы которых в мире примерно в 5 раз превышают запасы остаточной легкой нефти с малой и средней вязкостью. Поэтому в настоящее время актуальна разработка методов, способствующих наиболее полно реализовать потенциал месторождений тяжелой и высоковязкой нефти.

Магистерская диссертация посвящена вопросу исследования применения физико-химических методов увеличения нефтяной отдачи с использованием гелеобразующих композиций. В процессе выполнения работы исследуется влияние применения гелеобразующих композиций на коэффициент вытеснения нефти. Диссертация состоит из пяти частей: литературный обзор, экспериментальная часть, обсуждение результатов, финансовый менеджмент и социальная ответственность.

В первой части дипломного проекта рассматриваются общие сведения, связанные с нефтяной отдачей, приводится общая классификация методов увеличения нефтяной отдачи и более подробно изучаются физико-химические методы.

Нефтяная отдача – это отношение объема извлекаемой из пласта нефти к начальным запасам, содержащимся в пласте. Понятие нефтяная отдача подразумевает два вида: текущая и конечная. Нефтяная отдача – это отношение объема извлекаемой из пласта нефти к начальным запасам, содержащимся в пласте. Понятие нефтяная отдача подразумевает два вида: текущая и конечная.  Обычно нефтяную отдачу представляют в следующем виде:

$$К_{нефт} = К_{выт} * К_{охв} * К_{зав}$$

где $К_{выт.}$ – коэффициент вытеснения пластовой нефти;

$К_{охв.}$ – коэффициент охвата пласта разработкой;

$К_{зав.}$ – коэффициент заводнения залежи.

Физико-химические методы увеличения нефтяной отдачи делятся на 5 групп:

- вытеснение нефти водными растворами ПАВ (включая пенные системы);
- полимерное вытеснение нефти (растворами);
- щелочное вытеснение нефти (растворами);
- мицеллярно-полимерное вытеснение нефти композициями химических реагентов
- вытеснение нефти растворителями.

В работе исследуется влияние второй группы физико-химических методов, вытеснение нефти растворами полимеров, в частности с использованием гелеобразующих композиций.

Во второй части диссертации рассматриваются вопросы, связанные с подготовкой к проведению экспериментальной части работы, описанием используемого оборудования и осуществлением прикладных исследований.

Эксперименты проводились на установке физического моделирования неоднородного пласта в условиях, моделирующих начальную и позднюю стадии разработки пермо-карбоновой залежи Усинского месторождения, при температуре 60–200 °С.

Установка состоит из четырех основных частей:

– исследуемые жидкости (нефть, вода, гелеобразующий раствор);

– колонки с моделью карбонатного коллектора;

– контрольно-измерительные приборы;

– система поддержания постоянного давления и температуры в модели коллектора.

При исследовании фильтрационных характеристик и нефтевытесняющей способности композиций использовали насыпную модель пласта, состоящую из дезинтегрированного кернового материала или мрамора, пресную воду или модель пластовой воды Усинского месторождения с минерализацией 62.1-74.7 г/л и изовязкостную модель нефти Усинского месторождения (дегазированную термостабилизированную нефть с добавлением 30 % керосина).

Эффективность применения гелеобразующих композиций изучали при первичном вытеснении нефти и в процессе вытеснения остаточной нефти водой и паром из двух параллельных колонок с различной проницаемостью, а также в условиях, моделирующих пароциклическую обработку добывающих скважин.

В третьей части приводятся результаты проведенных фильтрационных испытаний, проводится анализ и интерпретация полученных данных. После анализа формулируются основные выводы, основанные на полученных зависимостях.

Термотропные композиции №1 и №2 образуют гели, которые могут блокировать прорыв воды или пара в добывающих скважинах с температурой 60-220 °С, выдерживать градиенты давления 60–140 атм/м. Предложенные гелеобразующие композиции №1 и №2 могут быть рекомендованы для ограничения водопритока в добывающих скважинах, применяться в широком температурном интервале, в том числе в совокупности с термическими методами увеличения нефтяной отдачи – при паротепловом и пароциклическом воздействии на пласт.

При закачке гелеобразующих композиций №1 и №2 в паронагнетательные, пароциклические или реагирующие добывающие скважины с забойной температурой от 60 до 220 ºС непосредственно в пласте происходит образование наноструктурированной системы "гель в геле" с повышенными вязко-упругими характеристиками. Это приводит к селективному ограничению водопритока, изменению направления фильтрационных потоков, снижению обводненности, ограничению прорывов закачиваемого рабочего агента в добывающие скважины. Ожидаемый результат – интенсификация добычи нефти и прирост КИН на 15%.

В четвертой части проведен расчет экономической эффективности закачки гелеобразующей композиции при режиме работы скважины в режиме реагентоциклики. Компания получает прибыль за счет дополнительного нефтевытеснения. Результаты расчета экономического эффекта показывают высокую эффективность данной технологии, получение существенного прироста прибыли за счет больших объемов дополнительного нефтевытеснения. Сроки окупаемости составляют менее одного года.

В пятой части дипломного проекта рассмотрена социальная ответственность лаборанта, проводящего прикладные исследования. Описаны виды вредного воздействия на окружающую среду. Проведен анализ всех опасных и вредных факторов рабочей зоны и возможности недопущения их проявления.

# A review on chemical flooding methods applied in enhanced oil recovery

In spite of the recent worldwide interest for alternative sources of energy, with especial and strategic interest in fuels derived from renewable products, the situation of petroleum in many countries stills drives much concern. Brazil, for example, is continuously advancing in the discovery of novel oil reservoirs and in the devise of potential ways to exploit oil both onshore and offshore. Many research projects are joining industry and university personnel, aiming to improve the technology to enhance oil productivity. In addition to the primary recovery techniques and several physical methods conceived as enhanced oil recovery (EOR) methods, the development of EOR processes based on operations which involve chemicals is greatly promising, many of which employing surfactants. Knowledge on the interfacial properties between oil, water and solid rock reservoirs, especially under extreme conditions, with occasional presence of natural gas, is important to better implement the EOR method. In view of this, surfactant-based chemical systems have been reported by innumerous academic studies and technological operations throughout the years as potential candidates for EOR activities. In this article, focus is given on recent advances effected by the application of chemical methods in oil recovery.

One of the most challenging activities in the petroleum industry refers to exploration and further exploitation of old and novel oil reservoirs. The intrinsic, natural capacity of fields to produce oil is promoted via primary recovery techniques. Due to physical constraints, e.g. reduced well pressure or high level of oil trapping, productivity is hindered and eventually ceases. During the recovery process, the original balance is perturbed and changes in the composition of the crude oil occur, which induce important effects on the reservoir wettability. At this point, provided economical aspects are observed and fulfilled, secondary and tertiary enhanced oil recovery (EOR) methods can be implemented, especially in locations where heavy oils or mature fields are encountered.

Mannhardt and Svorstol (2001) thoroughly investigated several reservoir cores (limestone, dolomitic limestone, calcitic dolomite and dolomite), to conclude that 15% of them were strongly oil-wet, 65% were oil-wet, 12% had intermediate wettability and 8% were water-wet. Bearing in mind that the majority of the petroleum reserves currently detected are accommodated in carbonate matrices, modification of the wettability of such reservoirs is a very important issue when further oil recovery is desired.

These EOR methods are devised with the purpose of overcoming the capillary forces which are responsible for the retention of a large amount of the residual oil in underground reservoirs, and are normally quantified by the Young-Laplace equations in Interfacial Sciences. Therefore, knowledge about the rock structure (typically, type of material and sizes and distribution of pores) is important to establish the extent of relative oil and water saturations, which are affected by the capillary pressure (Pc) generated thereby. In fact, capillary' pressure is a very useful parameter when classifying a rock sample as oil- or water-wet. Equation 1 gives the value of Pc in terms of the local interfacial tension, y, and the curvature of the interface (C), which is determined by the pore radius, R, and the contact angle, θ.

$$P_c = \gamma \cdot C = \frac{2\gamma \cos\theta}{R} \qquad (1)$$

Furthermore, surface wettability is intrinsically related to contact angle, particularly in the oil reservoirs, where often water, oil and gas phases may be in contact. The spreading coefficient a can be defined, as in Equation 2, in terms of the interfacial tensions developed between each pair of contacting phases, namely the solid-gas ($y^{SG}$ ), the solid-liquid ($y^{SL}$) and the liquid-gas ($y^{LG}$) interfaces, and is useful to describe the wetting properties of a rock matrix.

$$\sigma^{SLG} = \gamma^{SG} - \gamma^{SL} - \gamma^{LG} \qquad (2)$$

Direct measurements of yS(’ are rather difficult to make. However, when equilibrium is established at the contact point of all three phases, according to the finite contact angle 0 between the two fluids and the rock, then equation 3 holds:

$$\gamma^{SG} = \gamma^{SL} + \gamma^{LG}\cos\theta \tag{3}$$

The equilibrium pressure thus established can be altered by injection fluids during oil wells prospection. The composition of such fluids is based on mixtures of liquids and solids, in various compositions according to each specific application. Among the parameters to be observed when selecting the most appropriate fluid are pressure, temperature, chemical factors, economical factors and contamination levels.

Figure 10 is a simplified chart of some EOR methods normally carried out in petroleum exploitation activities. Many secondary methods basically involve perturbation of the unproductive reservoir via some physical modification, for example, water, gas or steam flooding, however with low final oil recovery. In particular, miscible and thermal methods can be useful to alter the viscosity and thereby the mobility of oil trapped in rocks due to some interfacial effect, with a combination of the above-mentioned capillary forces and viscous forces. As a result, more oil can be driven out of the pores. Thermal methods, for instance, mainly comprise steam injection or in situ combustion, but some specific techniques may be applied, either separately or combined with each other. In addition to the ones shown in Figure 10, one may cite the steam-assisted gravity drainage (SAGD), the wateralternating-with-gas process (WAG), the steam-alternating solvent process (SAS), the expanded-solvent SAGD process (ES-SAGD) and the vapor extraction process (VAPEX).

In all cases, it is important to consider the distribution of fluids in a reservoir (water, oil and even gas, which can be accommodated in a rock reservoir). This ultimately enables removal of oil via an appropriate extraction process. Therefore, surface properties like wettability must be investigated and properly accounted for. In the majority of oil reservoirs, water preferably wets the solid surfaces.

As far as surface properties are concerned, oil extraction activities are greatly optimized by EOR methods that employ some kind of chemical technique, and find huge applicability when secondary methods fail to improve reservoir productivity. Some of these techniques are cited in Figure 10, with particular emphasis to the ASP methods (AlkalineSurfactant-Polymer).

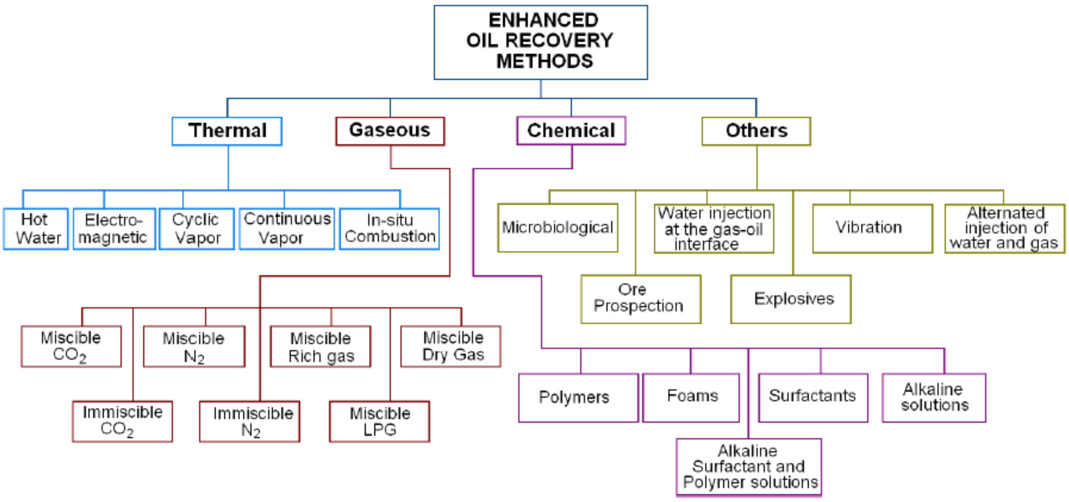

Figure 10 – Some enhanced oil recovery methods (LPG = liquefied petroleum gas).

The lowering of tensions between water and oil is the main driving force that enables the use of such methods. Changes in fluids viscosities upon addition of chemicals like polymer mixtures are also observed and present some advantages. Seawater injection may improve oil removal efficiency, partly because of varying ionic strength and surface charge.

Surface phenomena are ubiquitous in EOR activities. It is not surprising, then, that operations based on surfactant and/or polymer adsorption phenomena can be potentially advantageous, because of the interesting physicochemical properties of micellar solutions, emulsions, fracturing fluids and, in special, microemulsions. The ability of surfactant molecules to adsorb onto surfaces and modify their properties, and also to interact with polymers and other chemical species, creates many possibilities to be examined and tested. Also, the heterogeneous geological nature of the oil reservoir must always be considered when selecting a suitable chemical system to be used in oil recovery. Different surfactant and/or polymer molecules can be used with this purpose, but the search for the best system involves careful investigation on the formulation that provides the highest yields, especially in mixed systems. Compatibility between the different species tested, in terms of chain length, hydrophilic-lipophilic balance (HLB) and chemical nature for example, is one aspect to be initially examined. Furthermore, very extreme conditions established by varying pH, temperature, pressure and composition (salt and inorganic compounds) are encountered in the reservoirs, and novel surfactants with a potential to be used in EOR activities must support such conditions and interact favorably with other chemicals. Biodegradability is also desirable, as in alkylpolyglucosides and pyrrolidones. Regarding this, scattering techniques, surface tension measurements and calorimetric experiments, in particular, can be successfully carried out in order to provide valuable information on how surfactants and polymers, when mixed together under specific conditions, interact to provide certain final properties useful in EOR activities. When studying interactions between polymers and surfactants, an experimental parameter similar to the critical micelle concentration (CMC) is introduced as the critical aggregation concentration (CAC). At the CAC, a cooperative process develops whereby surfactant micelles are formed and become enfolded by the flexible polymer macromolecules. The reader is encouraged to consult some reports by Loh and co-workers for further explanation on such techniques and analyses of some experimental results with chemicals that can have potential applications in EOR.

A typical surfactant-based flooding process applied in petroleum fields is illustrated in Figure 11. Surfactant solutions are injected into an appropriate site, away from the production well, in order to create very low interfacial tensions that will enable the mobilization of oil trapped in the reservoir, when other nonchemical methods fail to improve the extraction efficiency. Normally, a mobile zone should be maintained, with propitious mobility ratios, and this can be achieved by incorporating polymers and alkali in the surfactant formulation, thus characterizing the ASP mixtures or solutions. An oil bank is then formed by the mobilized oil, which is ultimately driven to the production well for enhanced recovery.

In contrast, oil reservoirs could be damaged by insoluble residues left by the surfactantand/or polymer-based formulations, with obvious environmental impacts. In view of this, a continuously developing line of research aims to propose novel chemical systems to be used in EOR activities, with the purpose of minimizing or even eliminating this problem. The paramount importance of surfactant-based chemical systems, however, has been demonstrated by innumerous academic studies and technological operations throughout the years. In this article, we aim to focus on the recent advances obtained by the application of chemical methods in oil recovery.

### *Evolution of the chemical methods in eor activities*

In general, EOR chemical methods are classified in terms of the main chemical agents used to modify the equilibrium established in the reservoirs after recovery via conventional or physical methods. We particularly focus our attention on general EOR activities involving the use of polymers, surfactants, foams and certain chemicals such as alkali (see Figure 10), or suitable mixtures containing them, as in polymer-alkaline, surfactant-polymer and alkaline-surfactant-polymer (ASP) flooding mixtures. The aim in using such varied systems is to reach the target recovery factor for the 70% of the original oil in place which, in average, still remains in the reservoirs after conventional production, basically via a flooding mechanism which expels the oil out of the pores of the rock (for instance, the surfactant-based flooding process depicted in Figure 11).

In surfactant flooding, adsorption phenomena like chain interactions in solution and self-assembly, which affect interfacial tension and interfacial rheology and occur within the reservoir porous medium, play an essential role in determining the final oil recovery factor.

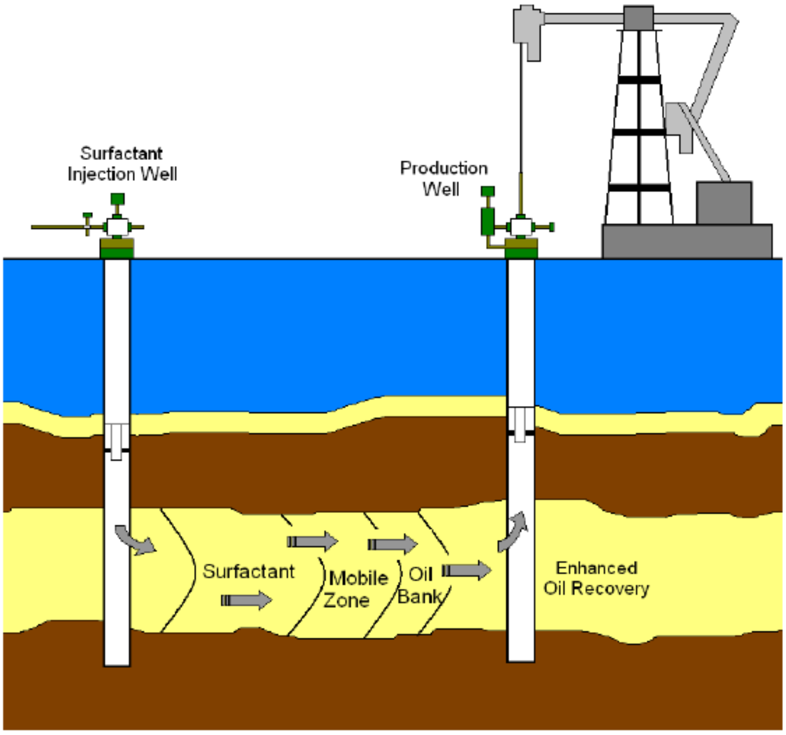

Figure 11 – Schematic of a surfactant-based flooding process applied to a petroleum field.

The efficiency of the process is reduced because of surfactant loss by adsorption, impairing the reduction of interfacial tension between residual water and crude oil, which ultimately renders the process technically unviable. It is reported on the literature that surfactants should be used at concentrations above the CMC for ionic molecules and around the CMC value for nonionic ones. In particular, when multivalent ions are present in the water, surfactant solubility may be hindered, via specific mechanisms which can be dependent on temperature. The choice of the more appropriate surfactant to be used in EOR applications, therefore, must also contemplate these aspects, as in the case of selecting or synthesizing a surfactant whose Krafft point is lower than the minimal temperature detected in the desired application.

Although applied in surfactantbased processes, for example with micellar solutions, emulsions or even microemulsions, this methodology is also suggested for other EOR activities employing chemicals, particularly when polymer-surfactant synergistic effects or interactions are to be investigated. This optimization or simulation approach has been frequently reported, as a means of reducing material loss or consumption and of increasing efficiency, allowing for selection of an appropriate EOR process based on the reservoir characteristics and intended results. This is particularly the case when chromatographic separation effects involving the surfactant molecules take place during specific applications, as in surfactant-alkaline flooding. Material loss is also caused by adsorption on reservoir rocks, precipitation and changes in rock wettability. The optimization also involves combination of different techniques, as reported by Babadagli and co-workers (2005), who indicate the use of a waterflooding process followed by injection of dilute surfactant solutions when dealing with a fractured carbonate reservoir containing light oil. These techniques, when combined, yield higher final oil recovery than the individual waterflooding or surfactant flooding methods.

Microemulsions are also potential candidates in enhanced oil recovery, especially because of the ultra-low interfacial tension values attained between the contacting oil and water microphases that form them. Microemulsion-assisted EOR injection was first attempted in 1963 by the Marathon Oil Company, which designed a process called Maraflood® . Later, in the early 1970's, Healy and Reed reported on some fundamentals of microemulsion flooding, especially viscosity, interfacial tension and salinity, relating the results on phase behavior of self-assembled systems to the Winsor's concepts.

The British Petroleum (BP) oil company devised a method whereby co-injection of a low-concentration mixture of surfactant and biopolymer is effected, denominated LowTension Polymer Flood (LTPF). Austad et al. (1994ab) discuss on the physicochemical aspects involved in this method, particularly on the importance of understanding the interactions existing within specific polymersurfactant and microemulsion systems applied in EOR. The studies of Austad and co-workers evolved during the 1990's on chemical flooding of oil reservoirs, with detailed reports on positive and negative effects of chemicals in oil recovery. These include: • Use of xanthan gradient at constant salinity in a three-phase LTPF process, in Berea sandstone samples, with alkyl-o-xylene sulfonate as surfactant, n-heptane as oil, and NaCl solution as injection fluid, observing chromatographic separation of surfactant and polymer under certain conditions; Adaptation of the LTPF process mentioned above to include the presence of xanthan and dodecyl-o-xylene sulfonate as surfactant in the aqueous mixture used as injection fluid, constituting a so-called lowtension polymer water flood (LTPWF) process, which is not effective if the surfactant concentration is relatively low; • Use of an alkyl propoxy-ethoxy sulfate-type surfactant in a LTPWF process, which is further enhanced by dissociative surfactantpolymer interactions in solution and by the effect of polymer on the flow performance of the surfactant in the porous media; • Investigation on the effects of physical parameters, like temperature and pressure, and system composition on the optimum conditions for application of multicomponent chemical systems in EOR;

• Experimental observation of the imbibition mechanism of brine solutions in water-wet or mixed-wed, low-permeable chalk material in the presence and absence of surfactant molecules, aiming for the recovery of oil originally found in the reservoir samples submitted to different aging times in the n-heptane-crude oil mixtures used; • Observation of the spontaneous imbibition of low-permeable chalk material with aqueous solutions of alkyltrimethyl ammonium bromides (cationic surfactants) and alkylpropoxyethoxy sulfates (anionic surfactants), which are capable of enhancing water wettability, enabling studies on both oil-wet and water-wet chalk samples ; • Use of chemical systems comprising xanthan and copolymers, alkylpropoxyethoxy sulfates, crude oil, n-heptane and synthetic seawater to observe dynamic adsorption phenomena of surfactants onto sandstone core samples, as an adaptation of the LTPWF process ; • Possibility to alter the original wettability of chalk reservoirs by tuning the properties of surfactant systems, namely the values of CMC, HLB and interfacial tension, besides any steric effects derived from specific surfactant structures, as in ammonium quaternary salts (e.g. dodecyltrimethyl ammonium bromide and similar molecules). As a result, imbibition rates may be altered and increase oil recovery rates.

In these reports, Austad and co-works have compared cationic, anionic and nonionic surfactants, showing that cationics are more efficient. Also, the paramount role of spontaneous imbibition, whereby capillary forces draw a wetting fluid into a porous medium, is evident in EOR activities employing surfactant- and/or polymer-based mixtures. This is opposed to the forced imbibition phenomena, which occur mainly due to viscous displacement (Babadagli, 2007).

The occurrence of imbibition via spontaneous mechanisms is especially interesting in fractured reservoirs. Morrow and Mason (2001) report on researches that indicate the use of surfactants expanding from laboratory to field tests. However many results are obtained for specific reservoirs, and much has yet to be understood. For example, the spontaneous water imbibition into oil-wet carbonate cores which present a wide variation in porous structure is reported by Standnes and co-workers (2002), who tested a nonionic ethoxylated alcohol and dodecyltrimethyl ammonium bromide as surfactants. This EOR process was efficiently implemented because of alterations in the wettability of the cores, from oil-wet to water-wet conditions. This is an important experimental result, since spontaneous imbibition usually will not occur in preferentially oil-wet reservoirs and the imbibition rates are generally low when surfactants are added, due to decreasing capillary forces occurring because of reduction in the oil-water interfacial tension. The surfactant CMC is again an important property that must be observed when designing its EOR application. According to the same authors, because the CMC decreases with increasing salinity at relatively low temperatures (ambient to 40°C), the oil recovery from oil-wet carbonate rock samples is delayed, which does not seem to be case when temperature is increased to around 70°C. Also, certain surfactants are more capable of changing the rock wettability from oil-wet to more water-wet conditions, like the cationic ones derived from coconut oil reported by Standnes and and co-workers (2002), and to less oilwet conditions, like the ethoxylated nonionic and anionic structures investigated by Ayirala and co-workers (2006), apparently below their CMC’s. This is a clear indication that all physical and chemical aspects involved in such applications must be properly accounted for.

Babadagli (2007) reports on the dynamics of capillary imbibition effected in Berea sandstone and Indiana limestone by mixtures of Triton® X-100 (a polyethoxylated nonionic surfactant), sodium chloride and polyacrylamide in different compositions, further enhanced by the action of heat, providing information on specific conditions that cause weak or strong capillary imbibition in both water- and oil-wet matrices. Later, Babadagli compared different EOR processes (waterflooding, thermal, and chemical with surfactant, with polymer and with NaCl brine) in the same rock samples (Berea, with 20% porosity and 500 milidarcies permeability; and Indiana, with 17% porosity and 8.5 milidarcies permeability) with respect to oil viscosity, matrix wettability and matrix boundary conditions. With Berea sandstone and heavy oil samples, significant increases in ultimate recovery and recovery rates were observed with the use of toctylphenoxypoly-ethoxyethanol as nonionic surfactant, as compared to the application of brine. These effects are far more pronounced than those detected with the Indiana limestone. In this case, only slight increases in recovery are noticed when the surfactant is added, the same being observed in assays employing polyacrylamide as polymer. Complementing these observations, Yildiz and co-workers (2006) also discuss on the effects that core shape have on spontaneous imbibition (cylindrical cores possessing the highest rates, square prism cores featuring intermediate ones, and triangular prism cores being the least effective). It should not be forgotten, however, that careful selection of surfactant structures and identification of the effects that surfactant properties have on capillary imbibition must always guide the implementation of the EOR process.

Interestingly, foams can be applied in EOR and stimulation activities with advantages over physical techniques, such as gas or steam injection, and surfactant- and/or polymer-based processes, provided tuning of the physicochemical properties of foams is undertaken in order to enable their technological applications. The main properties of foams which are exploited in EOR are higher viscosity than that of gases, their dispersed nature, which affects mobility and permeability in the porous medium, and low density, which helps reducing the effects of gravity forces, fingering and channeling flow, thereby improving the occupation in a heterogeneous reservoir and enhancing sweep and displacement efficiencies. In heterogeneous fracture systems, actually, the foam-assisted sweep efficiency can be improved by greatly reducing the amount of surfactant needed, due to fact that the foam will be able to occupy smaller fractures, thus requiring less surfactant solution. However, in low-permeability matrices (1 to 10 milidarcies), the rate and mechanism of foam propagation are not fully understood, partly because of limitations due to pressure gradients established after foam injection, which affect its stability. Moreover, Mannhardt and Svorstol (2001) highlight the necessity of selecting a suitable surfactant at a sufficient concentration required for foam propagation, which derives from surfactant adsorption on the reservoir surface, by combining propagation rate with foam viscosity and oil saturation.

In enhanced or tertiary oil recovery techniques, a profusive research area is dedicated to the design and implementation of novel chemical methods, mostly as adaptations of common processes already in place. In particular, mixtures of surface-active chemical substances can be incorporated in injection formulations, aiming for further oil displacement which can be effected by attaining ultra-low interfacial tensions and reduced fluid viscosity in the oil reservoirs. In this review, we have aimed to highlight some recent advances in the use of chemicals in EOR, focusing on the fundamental aspects involved in the reported applications. Knowledge about interfacial science, physicochemical properties of chemical systems and geological characteristics of the rock matrices is required in order to devise high-yield processes, often aided by optimization and modeling techniques. The technological importance of surfactant-based self-assembled systems is once again pointed out, as the central subject of the works carried out by many research groups throughout the years.

## Заключение

Проведен обзор методов увеличения нефтяной отдачи.

– Подготовлены модели неоднородного пласта пермокарбоновой залежи Усинского месторождения с газовой проницаемостью 0.8–6.3 мкм$^2$, с отношением проницаемости колонок модели в 1.5–4 раза. Проведено последовательное водо- и нефтенасыщение модели с определением порового объема.

– Проведены фильтрационные испытания модели неоднородного пласта и гелеобразующих составов №1 и №2 при условиях: интервал температур колеблется 60–200℃, скорости фильтрации − 1 мл/м, противодавлении − 19 атм.

– Установлено, что выравнивание и перераспределение фильтрационных потоков в результате применения гелеобразующих композиций способствует увеличению охвата пласта, что приводит к дополнительному вытеснению нефти благодаря вовлечению в разработку низкопроницаемого коллектора Прирост коэффициента нефтевытеснения составил по более низкопроницаемым колонкам от 8 до 39 %, в среднем 22%; по высокопроницаемым колонкам от 6 до 29%, в среднем 14 %; по модели в целом – от 6 до 39 %, в среднем 18 %.

– Рассчитана предполагаемая экономическая эффективность от применения технологии. Прибыль предприятия составит более 100млн.рублей за счет дополнительного отбора нефти, сроки окупаемости составляют менее 1 года.

– Оценены все возможные вредные и опасные факторы при проведении исследований.

Таким образом, исследованные гелеобразующие композиции могут применяться в широком температурном интервале, в том числе в совокупности с термическими методами увеличения нефтяной отдачи, при естественном режиме разработки и в режиме реагентоциклической обработки. Кроме этого, исследованные гелеобразующие композиции могут быть рекомендованы для ограничения водопритока и гидроизоляции добывающих скважин.