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Methods to Determine the Saturation State of the Mature Oil Reservoirs

Mihaela-Gabriela Zecheru*, Florea Minescu**

* OMV Petrom S.A. - ICPT Campina, Bd. Culturii 29, Campina
e-mail: mihaela.zecheru@petrom.com
** Universitatea Petrol - Gaze din Ploieşti, Bd. Bucureşti 39, Ploieşti
e-mail: florea.minescu@upcnet.ro

Abstract

The hydrocarbon reservoirs that are in an advanced stage of production, are of interest both due to increasing of oil demand and large investments that are needed in the discovery of new reservoirs. This interest is related to the knowledge of actual hydrocarbon saturation and to its distribution inside reservoirs.

The main objective of the paper is to present the investigation techniques and methods to determine the saturation state of the mature oil resrvoirs and to provide a set of rules and recommendations concerning their application on different reservoirs categories.

Keywords: *oil saturation, mature oil reservoirs, investigation techniques*

Introduction

The economic interest for the mature reservoirs is greater nowadays than in the past, and will be even greater in the future, considering the increase of oil demand. This interest is connected, first of all, to the actual hydrocarbon saturation and to its distribution inside reservoirs, for either rationalizing the production process, or infill drilling, or for the application of the IOR & EOR methods.

The mature reservoirs, namely the reservoirs that are in an advanced stage of production, represent a numerous category, not very clearly delimited yet. In other words, there is no quantitative criteria, like the field life, the recovery factor, the saturation state or others.

Reservoirs which are no longer producing could also be considered mature, if the possibility of production restart is considered, either by actualizing the production economic limit or by restoring the productive potential, as a result of the tertiary migration [1].

The main objective of the present paper is to provide a set of rules and recommendations for best identifying and quantifying saturation state from the mature reservoirs, by choosing the best methods and techniques for different reservoir categories and different ways of continuing production. The focus is not only the theoretical aspect, but also the practical one, several tests and applications are being performed on reservoir scale.

In the paper are presented the methods to determine the saturation for the mature reservoirs, along with the possibilities and limitations of application for each of them. Recommendations are made concerning their application on different reservoirs categories.

General Aspects Concerning Reservoir Rocks Saturation

Reservoir rocks and, generally, porous materials contain different fluids. Rock pores are entirely occupied by one or more fluid phases. How and how much do the fluids occupy the rock's pores represent the saturation state. Two ways of approaching this concept can be distinguished.

The first one refers to the proportion in which each of the existing fluids in the rock participates in occupying the pores volume and represents the saturation state at macroscopic scale. It quantifies through the amount of the saturation coeficients.

The second approach considers the way the fluid phases are distributed inside the pores, more precisely the place occupied by fluids inside the individual pores or inside the neighboring group of pores. This is the microscale saturation state. There is a connexion between these two, but not a strict dependency.

The irreducible water saturations form an important category, depending on a lot of complex factors. An extremely important factor is the porous space structure, especially the pore sizes distribution. Also, the absolute permeability, the interfacial tension, corroborated with the wettability contrast, the wetting hysteresis, the rock's water wetting or the oil wetting character, the clay minerals presence represent the other factors which are influencing the irreducible saturations value. Basically, determining the water irreducible saturation of a reservoir is very important considering that any physical model is asuming that this parameter is known.

Residual oil saturation represents another saturation category. A producing oil reservoir represents a process of oil displacement by water, gas or other injected fluids and, in some cases, a process of gravitational segregation. This process, as a result of the combined effect of pressure, friction, capillary and gravitational forces is not perfect, both at micro and macro-scale. Displacement imperfection results in what it is called the remanent saturation in oil.

The evaluation of the residual oil saturation is a difficult process. Simulation on rock samples of the ongoing or following to be active processes from inside reservoirs is often uncertain. The first disturbing factor is represented by restoration of the initial saturation state. It is difficult to obtain the initial water saturation, the usual displacement techniques are leading to higher saturations. Therefore, special techniques are required to obtain saturation correct values, but these techniques are not able to give a phase distribution in the pores reproducing the initial reservoir state. It is obvious that, even at a greater extent, the phase distribution in the pores during the flow simulation process is uncertain, and say nothing about the residual saturation. But, because no alternative methods are available, simulation becomes extremely important, especially when EOR technologies, very expensive and economically uncertain, are designed. The difference between the residual saturation before the process and the expected one allows the additional oil recovery calculation and grounds the decision to initiate or not such a process.

Another point regarding the residual oil saturation is its distribution inside the reservoir. An average value per reservoir is useful, but still more useful oil locating, knowing that, it does not matter the trap type, the rock and fluids properties, the reservoir's energy, the production system etc., as there are zones of different saturations into the reservoir. Even the initial saturation is characterized by this if we consider the capillary transition zones.

The techniques used to determine the oil saturation, no matter the moment they refer to (before production, after the primary production etc.), assume that the reference data is correct. This data refers to the geological-physical model, the production history, the displacing mechanisms etc.

Investigation Techniques and Methods for Setting the Saturation State

The saturation state in reservoirs can be approached from several points of view, depending on the scope. Thus, the objective may be the average oil saturation setting, the above, respectively below average oil saturated areas identifying, or the saturation maps drawing.

The material balance method

The material balance represents predominantely a method used to determine the hydrocarbon resources. As far as these resources can be determined by other means, the material balance equations can be also used for determining saturations. Usually, it is used to asses the independent hydrodynamic units, separately produced. The equations are customized according to the presence or absence of aquifers and/or the free gas caps, respectively for injection of different fluids comprised in the IOR/EOR methods. Sometimes, the material balance used for the drainage area of a well or of several wells is agreed.

The material balance equation can be also used to determine the residual oil saturation, if the oil reserve is estimated, namely the recoverable part of the initial oil in place. This can be graphically [2] or analytically [3] determined, and represents the current estimation method of the recoverable reserve.

Reservoir hydrodynamic investigation

Reservoir pressure is a key factor of production evolution and, implicitly, of the saturation state. Fluids saturation is not directly investigated by means of pressure measurements under non-stationary regime [4]. Measured pressures are an essential base for the use of the material balance equations and for production simulation, directly providing information on the saturation state. However, knowing that the hydrodynamic investigation provides the effective permeability that explicitly depends on saturation, and that there are relative permeability curves, by combining the two it is possible to obtain the average oil saturation of the investigated wells' drainage area. This is not a current practice, mostly because of the almost total lack of relative permeability curves, especially for the mature oil reservoirs.

This possibility, not really a method, of determining the oil saturation is limited to the case of separately producing enough homogeneous productive horizons. In the case of the simultaneous and not separated production of more than one horizon, this approach can be considered a total failure.

Tracer tests

Tracer is a substance not naturally found in the reservoir fluids, that can be transported by their flow through the reservoir and detected easily, even at low concentrations.

The practice of tracer tests is rather old in oil industry, such a test being performed first time in 1968 [5,6]. There are different types of tracer tests:

- IWTT (Interwell tracer test) are tests mainly aiming to determine fluids preferential flow paths inside reservoirs, the water channels, the geological barriers presence; no application concerning fluids saturation. Up to present, in Romania 70 tracer tests from this category have been performed on 30 different structures, all of them for monitoring the water injection process;
- SWCTT (Single-Well Chemical Tracer Test) and TWTT (Two-Well Tracer Test) are representing tests for determining the fluids saturation, performed in a well or between

wells; the ones between wells have the advantage of a much larger investigation area than the tests performed in a well.

In the case of tracers tests performed in a single well, SWTT, the basic principle is the following: the oil saturation calculation is based on the relative velocity of the two tracers dispersed in the porous space determination. Because the ratio of the two tracers velocity depends, first of all, on the oil saturation and on the relative solubility of the two tracers in water and in oil, the oil saturation can be calculated only if there are laboratory measurements of the relative solubility.

On well-site, a tracers test in a single well comprises of 3 phases: injection, reaction and production. So, the tracer (the ester) is injected in reservoir, in a producer, up to a certain depth according to the volume of the tracer solution used. After that, the well is shut-in in order to allow the ester to react with water from the reservoir and to be partial hydrolysed. This fact leads to occurrence of a new tracer in reservoir. The new tracer together with the ester form a couple of tracers, in a certain distance within the reservoir. Both tracers will be analised in the produced water after the well is put again in production. By measuring the produced fluid concentration, knowing the partition coefficient under the concrete conditions (fluids composition, temperature), the oil saturation of the area of tracer injection is measured [7,8].

Method can be applied to all types of tests, under the condition of controlling the area where the tracer was injected. The simultaneous opening of several productive layers limit the results accuracy. In Romania, there are concerns about the implementation of this kind of tests, that were first implemented in 2011 in two wells from Tazlău reservoir.

The second tracer tests category for determining the fluids saturation is represented by TWTT, that consist of injection of two tracers with different solubilities in water and oil, in a well and samples collection from reaction wells situated in the influence area of the first. In the case of these tests, the investigated reservoir volume is much larger and depends on the distance between the injector and the reactor. It is the only method of saturation setting that is independent of porosity. It has a good accuracy in many cases and provides information about reservoir heterogeneity, working for both old wells and new wells, either in cased or open hole wells.

In the case of tracer tests performed between two wells, the marker (landmark) method for test designing and for saturation calculating is being used. This method has been suggested by TANG [8] and it is based on the idea that, as the injected tracers have the same flow path in the reservoir, but need different time-intervals to arrive to reactors, the response curves of the two tracers should be similar. Saturation can be determined through the response curves (tracer concentration variation with time in the production well), if a marker moment (of appearance) is chosen on each curve. In Romania, two tracers test of this category have been performed up to now. First test has been performed in 2005 on Taşbuga reservoir, and the second one in 2011 on Tazlau reservoir.

Geophysical methods

The geophysical methods are representing one of the most important, if not the most important, instruments of reservoir data acquisition. Correctly calibrated and interpreted, they can provide a very large range of data of regional scale, of reservoir scale, between the wells and the surrounding area. Fluids saturation is one of the determined parameters.

Conventional geophysical methods

The conventional method of water saturation evaluation on the classical resistivity log consists in applying ARCHIE's second law. Deviations, sometimes very important, have created a whole literature [9-11]. However, the success of these trials only was and is a partial one, because the saturation state on micro-scale, that phases disposal in pores, has been left aside or considered as unimportant.

Being more an intuition than an understanding, the saturation state at micro-scale concept could be validated by CrioSEM method [12]. Other investigations on micro-models have completed the image of phases disposal in pores under a dynamic regime [13-15].

Reinterpretation of existing geophysical logs by using modern techniques

The current issue of the mature reservoirs is that the number of new wells from where we can get new information is very limited. Instead, there is a vast archive of more or less old recordings. At least a part, maybe the largest one, is interpreted in accordance with the respective days theories and models, that is the one of ten years ago. Although not a current practice, the re-interpretation of the old information (not necessarily the well geophysics ones) may offer new or more accurate data by using the actual knowledge. The best example is that, before 1965, the electric logs were mainly used for correlating the geological information, not for determining lithological or petrophysical characteristics.

Starting from this consideration, V. Negoiță [16] suggests a methodology for re-interpreting these logs. This methodology was applied in certain wells from Oprişeneşti, Ciolăneşti, Băbeni, Ciureşti and Țicleni structures.

Besides the value itself, the re-interpretation of the old logs is also helping the new methods, such as the ones used in investigating the cased wells, presented below. For a complete analysis, the actual saturation determination must be accompanied by knowing the initial one, impossible for the mature reservoirs, excepting the cases, themselves scarce, where laboratory determinations exist.

4-D Seismic

In 3-D seismic, the data gathered is used for characterizing the hydrocarbon reservoir at the moment of seismic investigation performing. If a second 3-D seismic is done for the same reservoir, but at a future moment, we can speak about a 4-D seismic. This type of investigation is used to characterize the reservoir's dynamic evolution, respectively the alteration with time of the fluids contact position, evidencing the reservoir depletion, evidencing the not swept areas in the case of different agents injection into reservoir. Usually, several 3-D seismic investigations are performed at intervals of some years, much better results being obtained in case of combining the 4-D information with other information (numerical simulation, new wells drilled on the structure, different other investigations performed in the reservoir).

The main factors influencing the 4-D seismic applying are:

- reservoir thickness (reservoir has to be thick enough for the saturation changes to be noticeable);
- possibility to place sources and receivers in the same positions (small position changes lead to a high noise level).

RMN method of determining the saturation state around wellbore

The RMN method is based on the generation of a permanent magnetic field around the well and the transmission, by means of an antenna, of a radio waves pulse generating an oscillating magnetic field. Signals coming from the hydrogen atoms protons resounding in the permanent magnetic field are recorded.

The use of methods based on the nuclear magnetic resonance provides different information for hydrocarbon reservoirs petrophysical characterization, for example: oil and water saturation, total and effective porosity, information concerning pores geometry, irreducible water volume, corrected TIMUR – COATES permeability for hydrocarbons, mobile and immobile fluids volume, etc.

The non-dependence on water salinity makes this method very valuable compared to the other methods which are based mainly on resistivity measurements. More than that, the method imposes very few restrictions on the wellbore geometry and work temperature, so it can also be used in deep wells, and for the EOR methods applications monitoring [17].

Combined with resistivity measurements, it can provide very accurate information from very thin formations, otherwise difficult to describe using the logs [18].

Electromagnetic investigation between wells

This method is based on the resistivity contrast between hydrocarbons, which are resistive, and the reservoir water, which is conductive.

This investigation method can be best applied on the dynamic reservoirs, where the fluids saturation changes with time and space. These are the reservoirs where water or other substances have been injected, and, as an immediate result, the areas not swept by the injection fluid can be identified, information on the high porosity or compact areas can be obtained.

The resistivity variation from the initial moment (recorded on the original logs) to the actual one is associated with water saturation and mineralization changes, following the water injection. Its control is somehow uncertain concerning the salinity altering effects. Another uncertainty results from here, concerning the association of a high resistivity to the highly oil saturated intervals presence.

Geophysical investigations in cased wells

The analysis performed behind the casing is representing a modern instrument of geophysical data acquisition, with a special application to the old wells and mature reservoirs; for the new wells it works in case of well stability problems or wells drilled through casing. Data acquisition from wells which have not been investigated at the initial moment, or from investigated wells having incomplete or uncertain results, represents a special importance.

These methods have different commercial denominations, depending on the services company. Fluids saturation is one of the parameters that can be determined. This is an enormous gain to highlight the not perforated or not depleted productive areas, to determine the residual oil saturation, to monitor production or to watch upon the saturation variation during the conventional production or application of different IOR/EOR technologies. Another advantage of these methods is that data is quantitatively and qualitatively interpreted, offering results in an useful format for both geophysicists and reservoir engineers.

One of the first possibilities of investigating a cased well, is the neutronic impulses logging [19]. There are more application alternatives. The „classical" one is to determine the carbon/oxygen ratio [20], almost not sensitive to low or following injection variable water salinity. The TDT method (Thermal Decay Time) [21] is giving good quality saturation measurements when water salinity is at a high level (> 35,000 ppm), constant and known. A common limitation to these two alternatives of the neutronic impulses logging is their use without tubing in the well, which implies shutting-in the well, with all negative consequences resulted.

In order to diminish the above mentioned limitations, these two alternatives have been integrated into a single device, called Reservoir Saturation Tool, which is lowered through the tubing [22]. Additionally, this instrument can determine the water/oil ratio in the tubing or the areas of oil or water accumulations in the horizontal wells.

Several measurements have been performed in Romania. One example is Taşbuga reservoir, where 4 wells have been investigated. The most important result of the logs is the indication of the highly oil saturated intervals that should be perforated or re-perforated for a better communication between the formation and the well.

Such kind of determination can be validated through complementary measurements, such as the tracers tests in a single well. Also, for the not perforated areas, the comparison with the results obtained from the open hole logs interpretation or re-interpretation is interesting.

Another technology is the measurement of the rock resistivity in the cased wells. The principle of this method is similar to the laterolog logging [23]. It is a differential method, the most important part of the signal being transmitted through the casing string. The measurement is done under static regime because the background noise exceeds the measured value of the electrical signal by 10^4 times. This is an important limitation of the method: the electrodes-casing contact must be perfect. In the same time, this limitation is accompanied by the advantage that the fluid in the well can be of any type. Another limitation of the method is the sensitivity to resistivity and to the cement annulus thickness.

Production simulation

The most comprising way to determine saturation in a reservoir is production simulation. The simulation process is a very complex one, both technically and economically [24]. The saturation state is determined during the stage called *history matching*, comprising the pressure and then the saturation matching. *Saturation matching* is done successively for water and gas. Each has, as a first stage, the matching of the breakthrough time (*breakthrough*) and then the matching of the water/oil, respectively gas/oil ratios for each well.

The modern commercial simulators are performing as never thought in the past, mainly due to the increasing calculation power, and also due to reservoir characterizing modern tools, to the special core analysis and to the geophysical methods. Important steps have also been made concerning the advanced reservoir characterization. The remaining problem is the personnel that should be able to feed the system with appropriate data, by filtering the available one and choosing the best methods of completing the necessary data and adapt the simulator for each reservoir studied. The reservoir engineer's part in the simulation process is essential for optimizing it and avoiding certain errors. A not enough grounded calibration may lead to deceiving forecasts.

Mohaghegh method for oil saturation evaluation

The methods of production data analysis have been significantly improved lately. These methods are being used to offer indications concerning reservoir permeability, fractures length, fractures conductivity, drainage area, gas initial resource, estimated oil cumulative production and the skin factor. Even though there are many available methods, none of them is always giving the most accurate results.

In a remarkable work, Mohaghegh and others [25] presents a „step by step" procedure of production data intelligent analysis (IPDA). This method, in order to be 100% valid or close, some comments have to be made. IPDA was conceived for the specific situations where only production data were available. So, if we have access to other data like logs, cores, pressure tests, geological models etc., other methods can be used. On the other hand, it was demonstrated that data similar to the one above can be used for enhancing the present methods accuracy.

IPDA is an iterative optimizing method, so evaluation takes quite a while. There are 4 distinct and interconnected steps: the decline curves analysis, the type-curves matching, reservoir simulation for one well (production history matching) and the graph representation of reservoir's relative quality, that includes 3D maps of the remained hydrocarbon resources.

Elaboration of Selection Criteria for the Investigation Techniques and Methods of Determining the Saturation State

For comprehensively and, at the same time, particularly treating of the reservoirs and making the correspondence between them and the existing methods, a reservoir classification together with a methods classification concerning the aimed objectives are necessary.

Many classification criteria of the reservoir can be found. We are going to define four criteria, namely: resources volume and their economic importance, production system, characterization degree and a geological criterion accounting for lithology, structure and tectonics.

This small number of categories have been chosen for better organizing the information. Reservoir categories and their codes are showed in Table 1.

Next, it is suggested a classification of the scopes the saturation evaluation is done for, by defining several saturation categories, presented, along with their codes, in Table 2.

Table 1. Reservoir classification and their codes

i According to resources volume and their economical importance	Z.I. Very important reservoirs Z.II. Important reservoirs Z III. Marginal reservoirs
ii. According to the production system	Z.1. Primary production Z.2. Secondary production Z.3. Tertiary production
iii. According to the characterization degree	Z.a. Advanced characterization Z.b. Medium characterization Z.c. Poor characterization
iv.According to the lithology, structure and tectonics	Z.α. Homogeneous not compartimented reservoirs Z.β. Highly heterogeneous not compartimented reservoirs Z.γ. Reservoirs compartimented by folds and/or faults Z.δ. Layered reservoirs Z.ε. Fractured reservoirs

Table 2. Saturations classification as a function of the aimed objectives

Code	*Saturation category*	*Code*	*Saturation category*
IRS	Irreducible water saturation	ARS	Average reservoir saturation
ROS	Residual oil saturation	RSM	Reservoir saturations map
NWS	Water/oil saturation close to the well	MTZ	Mobile oil in the water/oil transition zone
DAS	Drainage area saturation	HSZ	Highly oil saturated areas
IWS	Saturation between wells		

The targets of the different saturation categories can be reached by one or more existing methods. Such approach, that takes into consideration the potential of saturation determining methods is presented in Table 3.

Recommendations from this table have a general character. The different reservoir particularities may alter or invalid these properties. This is why this table is only a guide. Other recommendations on using different methods of saturation determining, containing additional details, are presented in table 4, in which are shown some limitations of these methods, and also it is given their investigation depth [9].

Table 3. Correspondence between the scope of saturation evaluation and the methods of determining it

Method	Code	Determination objective								
		IRS	ROS	NWS	DAS	IWS	ARS	RSM	MTZ	HSZ
Laboratory methods	LM	First	First							
Material balance	MB				Second		First			
Hydrodynamic investigations	HI					Second				
Tracers in a single well	TS			Second	First					
Tracers between wells	TM					First				
Production simulation	RS							First		First
Mohaghesgh method	MG						Second	First		Second
Conventional logs	CL	First	Second							
Logs reinterpretation	RL			First						
Reservoir saturation tool	ST	Second	Second	First					Second	
Electromagnetic investigation between wells	ET				Second	First				
Resistivity behind casing	RC			First						
Neutron pulses log	PN		First							
4-D seismic	4D						Second	First		First

First recommendation (red)   Second recommendation (yellow)

It goes without saying that, in order to apply any of the saturation determining methods, no matter its category, different information is needed. These can vary considerably from one method to another. In principle, each reservoir has its individual features, is part of more or less known areas, concerning genesis, concerning the inter-relation with the neighboring reservoirs and the preserving of mutual characters. On the other hand, information concerning reservoirs may be direct (the normal case) or estimated. For all of them, an accuracy degree should be established, which is sometimes difficult, sometimes impossible, mostly because we are speaking about mature reservoirs. Any piece of information has to be filtered prior to entering into the database and necessary to apply one or the other methods of saturation determination.

Preliminary reservoirs selection

After ranking the reservoir as belonging to one or the other of the mentioned categories, its potential should also be cheked to see how interesting the saturation state determination is.

At a first look, the best criterion would be the average oil saturation. This information is important and indispensable. It represents, essentially, the specific leftover resource, and it is representing the base of the left over resource calculation. A correct geological-physical model and reliable production data allow a good evaluation of this parameter.

Knowing that the displacement efficiency varies may vary from one reservoir to another, the possible efficiency of the production process set for the respective reservoir is to be determined. In other words, the residual oil saturation has to be determined.

Table 4. Recommendations and limitations in using the saturation determining methods

Method	Usage recommendations	Limitations	Investigation depth	Observations
Laboratory tests	Irreducible water saturation Residual oil saturation IOR/EOR displacement tests	Representative samples Reservoir conditions simulation Special equipment	<25 cm	Highly qualified personnel
Material balanced	Fluids average saturation Complementary method of production simulation	PVT analyzsis and pressure measurements availability	Whole reservoir	Works for a well, a group of wells or entire reservoir
Hydrodynamic investigations	Oil displacement by water injection Oil saturation in the transition zone	Early phase of injection High heterogeneity Wells interference	Well drainage area	Unusual interpretation procedure
Chemical tracers	Oil saturation in the drainage area Saturation between injector and reactor	No saturation distribution data available Presence of channelling Time consuming	7,5-12 m SWCTT Well to well distan-ce TWTT	High potential for Romanian reservoirs
Production simulation	Very well characterized reservoirs High potential reservoirs (primary, IOR/EOR)	Expensive software Very accurate data	Whole reservoir	Highly qualified personnel
Mohaghesgh method	For very poor data base	Reliable production data No software	-	Method is not enough developed
Conventional geophysical methods	Irreducible water saturation in open hole	Drilling fluid type Size of borehole Contamination is persent	0.6 -15 m	Alternatives adapted to specific conditions
Old logs reinterpretation	DRR log correlated to actual logs	Only for fresh fluid Sandy formations of low resistivity	-	Adequate corrections of the acquired data
Neutron pulses logging (for open and cased hole)	Gas and oil saturation Water/oil/gas contacts Mostly in cased hole	Low water salinity Known water mineralization	17.5 – 60 cm	Best method for gas saturation
Magnetic nuclear resonance method	Irreducible water saturation Water and oil saturation profile close to the well	No limitations are imposed by water salinity	0.6 m	Investigates the area from behind the contaminated one
Electromagnetic tomography between wells	Oil saturation profile between wells Saturation modifications from the initial one	Salinity affects the saturation values	-	Cased and not cased wells
Resistivity in cased wells	Formation saturation under various conditions Injection monitoring	Depends on cement thickness and resisitivity and on casing dimension	-	Can operate when oil or gas is present in the well
4-D seismic	Saturation profiles in reservoir Saturation variation with time	Difficult to apply on shore Great reservoir thickness	-	Relatively expensive

The two average saturation values or value-intervals is allowing us to calculate their difference. This difference represents the target of the future production, meaning that it allows the calculation of the recoverable oil quantity, the main parameter of the economic evaluation that eventually makes the decision of production continuing or of an IOR or EOR technology application.

Mature reservoirs management often focuses on identifying the mobile oil areas and on selecting the minimum conditions leading to a new economic development by side-tracking the existing wells.

The high oil saturation locations identification is only the first and the most important step. The process is difficult because of the quantity and quality of the data available for mature reservoirs. This is why, after the first selection of potented reservoirs, acquisition of additional data and performing a detailed study should be done afterwards. This study should be based on an adequated geological model correctly describing the trap type and reservoir genesis. Usually, logs, core and fluid analysis, facies descriptions, initial resources, cumulative productions, structural maps are available, all being more or less reliable. Data about the productive formations opening and knowledge of wells behavior are also very important.

After identifying the highly oil saturated area, an economic value is calculated by estimating certain parameters of a lower accuracy degree. If such an approach leads to a negative result, then the project is abandoned. Conversely, a positive result is only a hint of confirmation of the feasibility of achieving such a project, the final verdict can be both positive or negative.

Setting an investigation method selection grid depending on reservoir's category

This attempt is taking into account only a systematization of information. It can be only partially, considering that, on one hand, reservoir classification is based on a small number of criteria and, on the other hand, the conditions of applying the determination methods have a lot of particularities. The connection between the reservoir categories and the most appropriate methods of saturation evaluation is presented in Table 5.

Table 5. Correspondence between reservoir category and the methods of saturation determination

Reservoir type		Z.I			Z.II			Z.III		
		Z.1	Z.2	Z.3	Z.1	Z.2	Z.3	Z.1	Z.2	Z.3
Z.a	Z.α	RS;4D	TM;RS;4D	TM;RS;4D	MB	TM;MB;HI	TM;MB	MB	MB	X
	Z.β	RS;4D	TM;RS;4D	TM;RS;4D	MB	TM;MB;HI	TM;MB	MB	MB	X
	Z.γ	RS;4D	TM;RS;4D	TM;RS;4D	MB	TM;MB	TM;MB	MB	MB	X
	Z.δ	RS;TM	RS;TM	RS;TM	MB	MB	MB	MB	X	X
	Z.ε	RS;4D	RS;4D	RS;4D	MB	TM; MB	TM;MB	MB	X	X
Z.b	Z.α	MB;4D	TM;MB;4D	MB;4D	MB	HI;EM;BM	X	MB	MB	X
	Z.β	MB;4D	TM;MB;4D	MB;4D	MB	HI; EM;BM	X	MB	MB	X
	Z.γ	MB;4D	TM;MB;4D	MB;4D	MB	TM;BM;	X	MB	MB	X
	Z.δ	MB;EM	TM;EM	EM	EM	EM	X	EM	EM	X
	Z.ε	MB;EM	MB;EM	EM	EM	EM;BM	X	EM;BM	X	X
Z.c	Z.α	RL;MG;4D	RL;4D;EM	RL;4D;EM	MG;RL	TM;RL;EM	X	MG;RL	TM;EM	X
	Z.β	RL;MG;4D	RL;4D; EM	RL;4D; EM	MG;RL	TM;RL;EM	X	MG; RL	X	X
	Z.γ	RL;MG;4D	RL;4D;	RL;4D;	MG;RL	RL;TM	X	MG;RL	X	X
	Z.δ	RL;EM	RL;EM	RL;EM	RL;EM	RL;EM	X	RL	X	X
	Z.ε	4D	4D	4D	MG	MG	X	MG	X	X

Notes

1. Some additional restrictions could eliminate a certain method
2. The well geophysical methods are not in the table, being very usual
3. Production simulation method include the material balance
4. The single well tracer method is used in all R1/α,β,γ reservoirs

Legend

First recommendation

Second recommendation

Excluded X

The reservoir saturation state analysis does not constitute a separate study, in spite of its clear and obvious objectives. This study must be integrated to a larger effort of reservoir characterization. Reservoir's heterogeneity description has to play an important role, from the micro to the regional scale. Reservoirs with a high heterogeneity degree, be they silice-clastic or carbonate, have the highest development potential because the usually poor efficiency of both the primary production and the secondary one. It is obvious that the technologies applied up to evaluation time have a major impact on the evolution and current state of saturation respectively on the development potential and recoverable reserves.

Another important aspect that has to be included into the efforts for determining the saturation state is the reservoir energy level, mainly expressed by the reservoir pressure value. Identification of a development potential, mostly under the condition of a small reservoir pressure, has to be connected to the possibilities of applying the IOR/EOR methods.

Conclusions

1. The paper performes a review of the methods for the reservoir rock saturation determination. A synthesis relating to the application recommendations as well as their limitations was achieved.
2. Another synthesis reffers to the different saturation category (irreducible, residual etc.) in relation with the recommended measurement methods. A summary table have been proposed, which could be useful for selecting the appropriate methods of saturation determination as a function of reservoirs characteristics.
3. The correspondence between the mature oil reservoir category and the available methods of saturation determination, in a hierarchical manner, as a comprehensive table, was devised.

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Metode de determinare a stării de saturație din zăcămintele de țiței mature

Rezumat

Zăcămintele de hidrocarburi aflate într-o fază avansată de exploatare, prezintă interes atât datorită cererii crescânde de țiței cât şi investițiilor mari ce sunt necesare in cazul descoperirii de noi zăcăminte. Acest interes este strâns legat de cunoaşterea saturației în hidrocarburi şi de distribuția acesteia în cuprinsul zăcământului.

Obiectivul principal al lucrării constă în prezentarea tehnicilor de investigare si a metodele de determinare a stării de saturație în zăcămintele de țiței mature, precum şi furnizarea unui set de reguli şi recomandări privind aplicarea lor la diferite categorii de zăcăminte.