MultiScience - XXX. microCAD International Multidisciplinary Scientific Conference
University of Miskolc, Hungary, 21-22 April 2016, ISBN 978-963-358-113-1

THE EFFECTS OF POLYMER-TENSIDE FLOODING ON SECONDARY OIL PRODUCTION IN SANDSTONE RESERVOIRS

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INTRODUCTION

The most important question that is asked when a reservoir is being produced is that what its final recovery factor be. What will show the volume of remaining fluid that cannot be produced by primary and secondary production methods. This residual oil saturation can be further decreased, if the reservoir's original properties (saturating fluids viscosities, wetting, etc.) are modified in a way that increase in produced oil volume can be achieved. This additional production can only be obtained, if the so called tertiary EOR (Enhanced Oil Recovery) production methods are applied in the field.

Reservoir engineers all over the World throughout the last few decades were working to increase effects of these tertiary methods and find those applications where most satisfying results could occur.

This paper contains and discusses effects on final production ratios of sandstone reservoirs regarded to polymer-tenside flooding EOR method which were measured during displacement measurements made in the laboratory of Research Institute of Applied Earth Sciences.

SHORT INTRODUCTION OF EOR METHODS

Many types of Enhanced Oil Recovery methods are known but all can be sorted into three major groups, which are Gas miscible, Thermal and Chemical. But as basis for all methods it can be said that some sort of material (or materials) is (are) injected into the reservoir that will effect beneficially some of the existing parameters of fluids present and those rocks that contain them which will cause increase in production of hydrocarbon. This injected material can change the composition of oil (Gas miscible), or reduce the mobility ratio between the fluids, by heat injection (Thermal methods), or even change properties such as wetting by the modification of wetting angles (change of interfacial tensions) between the fluid-fluid and fluid-rock surfaces. All existing EOR methods are listed in ***Table 1*** **[1]** by the effects they are causing in order of enhancement in production.

DOI: 10.26649/musci.2016.009

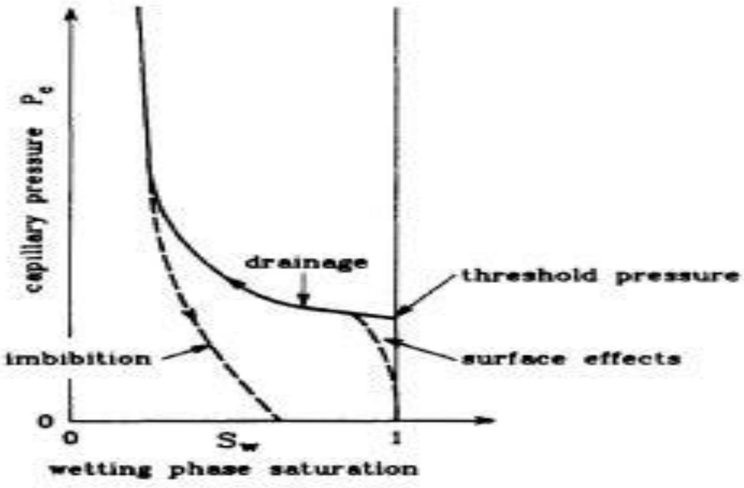
Table 1
***EOR methods* [1]**

Method			Reduction of mobility ratio	Reduction of S_{or}	Modification of pore structure	Remark
1.	Gas miscible	LPB. rich gas, CO_2, N_2, fuel gas, etc.		+ +		Reducing of interfacial tension
2.	Thermal	Hot water	+			Reducing of oil viscosity
		Steam	+ +	+		Reducing of oil viscosity and of interfacial tension
		In situ combustion	+ +	++		Reducing of oil viscosity and of interfacial tension
3.	Chemical	Polymer	+ +		+	Increasing of water viscosity and modification of pore structure
		Micellar-polymer	+	+ +	+	Reducing of interfacial tension (increasing of water viscosity and modification of pore structure)
		Caustic		+		Reducing of interfacial tension and change of wettability

In our case displacement measurements were taken in order to determine the secondary oil production achieved by polymer-tenside flooding on samples taken from the given sandstone reservoir. In the following the results of 5 measurements by the names ***EOR-1***, ***EOR-2***, ***EOR-3***, ***EOR-4*** and ***EOR-5*** will be discussed regarded to these core samples.

DISPLACEMENT MEASUREMENTS

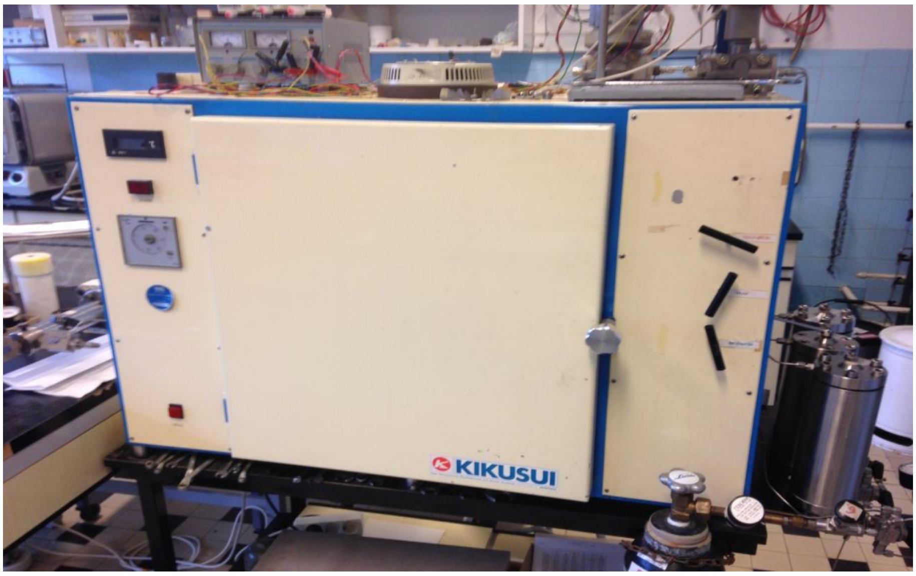
Displacement measurements are used to model saturation level changes which are present throughout the life of a hydrocarbon reservoir before, during and after production. Changes of saturations can easily be demonstrated by the capillary hysteresis curves of an oil-water two phase system (***Graph 1*** **[2]**). Where hydrocarbon migration is demonstrated by the so called drainage curve and those effects that are present throughout production are represented by the second curve which is titled as imbibition curve.



Graph 1
***Capillary hysteresis curves* [2]**

Saturation changes are measured on samples that have a lengths of 20 cm, which are artificially made by using 3 core samples with similar porosity (ϕ) and absolute permeability (k_{gabs}) measured by Nitrogen. These cores are put inside a Hassler type core holder (***Picture 1***) that can be pressurized to initial reservoir pressure (P_i) and placed inside of an oven (***Picture 2***) which heats up the system to initial reservoir temperature (T_i).

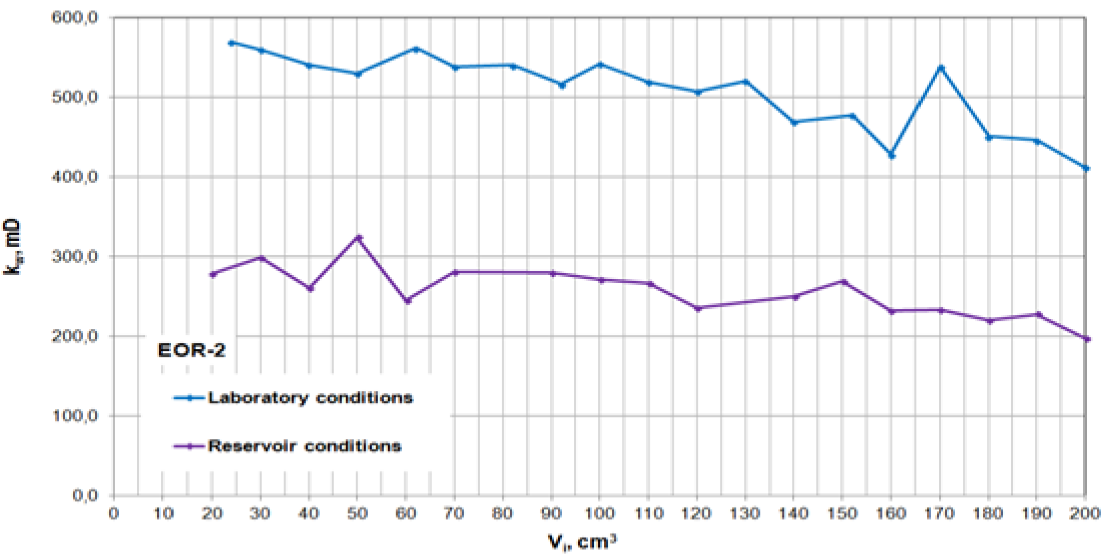
Picture 1
Hassler type core holder



Picture 2
Heating system

The displacement procedure can be divided into 4 phases which are the following.

Phase 1. Where absolute permeability regarded to the wetting phase (water taken from the aquifer) of the sample at laboratory and at reservoir conditions ($\boldsymbol{P_i}$, $\boldsymbol{T_i}$) are measured. After this phase it can also be noted that water saturation level will reach 100% (**S_w=1**) at reservoir pressure and temperature, which conditions refer to those that were present inside the pore system before migration of hydrocarbon had happened.



Graph 2
Water permeability of sample EOR-2

As it can be seen in ***Graph 2*** blue line indicates permeability values measured by water at laboratory, purple line at reservoir conditions in case of sample ***EOR-2***. This change is caused by the effects of increased heat and pressure which are present in the porous system. These effects cause aquifer water to flow in the same system with a much higher restriction than at normal laboratory conditions.

Phase 2. Models effect of oil migration inside the pore system, which at the procedures end will reach saturation levels of S_{wc} (connate water saturation) and S_{oi} (initial oil saturation) at the given sample. Which were those saturation levels that were present inside the reservoir before production. These saturation levels are reached in a way that the displacement of wetting fluid (water) by the non-wetting fluid (oil) is continued until the point when only non-wetting fluid is flowing out at the outlet side of the core.

Phase 3. Will simulate effects of production (imbibition) in which water (wetting fluid) will be injected into the sample with S_{oi} and S_{wc} saturation levels until no oil production is further recorded only displacing fluid will be present at the outlet side, and by this reaching those final saturation levels equal of S_{or} (residual oil saturation) and S_{wmax} (maximum water saturation). These saturations are present at that point of the reservoirs life cycle when pore system will contain that volume of oil that can only be further decreased by application of EOR methods. At this point the final E_D (Displacement efficiency) for primary production methods have been reached.

Phase 4. Contains the injection of polymer-tenside slug which will further increase the final recovery factor. The ΔE_D difference in the Displacement efficiency of the primary and tertiary production methods is measured regarded to the Original Oil In Place (S_{oi}) and not the S_{or}. This part is separated into to injections which are made continuously.

At first the polymer-tenside slug with given concentration and size (regarding to the pore volume V_p of sample) will be injected into the pore system.

After that following water will be injected in a given V_p volume to displace the slug and produce additional oil.

Note that in measurements number ***EOR-1***, ***EOR-2*** and ***EOR-3*** the polymer and tenside being used had concentrations of 1 g/l and 15 g/l and were injected in one single slug in a mixture. While in measurements number ***EOR-4*** and ***EOR-5*** concentrations of these elements changed also they were injected in multiple separated slugs but at a continuous phase.

DISCUSSION OF THE MEASUREMENTS

As part of the laboratory experiments there were a total of 5 samples (15 cores) measured. Where the first 3 measurements had same concentrations of polymer-tenside slug injected and the slugs and following waters cumulate injected volumes were equal 3 V_p volume. Because of this the first 3 measurement had the following scenario listed in ***Table 3***. For the last two measurement, there were multiple slugs injected where some slugs had polymer-tenside other had only polymer content. The scenarios of these two measurements are also described in ***Table 3***.

Table 2
Measured sample parameters

Sample	**V_p, cm^3**	**ϕ**	**k_{gabs}, mD**
EOR-1	25,093	0,3208	621,50
	23,261	0,2976	585,87
	25,937	0,3368	512,69
EOR-2	22,824	0,2924	546,61
	23,107	0,2948	616,56
	24,036	0,3104	670,82
EOR-3	17,116	0,2200	740,96
	25,310	0,3298	846,05
	25,704	0,3309	861,64
EOR-4	23,342	0,3048	630,49
	23,318	0,3013	686,32
	22,951	0,2996	633,41
EOR-5	22,720	0,2939	566,17
	23,614	0,3139	534,86
	23,102	0,3027	494,09

The aim of these multiple scenarios were to describe which is more preferable condition when taking into consideration of slug size and orientations of slugs at a constant concentration. The parameters of the samples used are listed in ***Table 2***.

Table 3
Scenario of the measurements

Sample	Displacement of water by oil	Displacement of oil by water	Polymer-tenside slug injection	Following water injection
EOR-1	1 V_p	1 V_p	1 V_p 1/15 g/l	2 V_p
EOR-2	1 V_p	1 V_p	0,75 V_p 1/15 g/l	2,25 V_p
EOR-3	1 V_p	1 V_p	0,5 V_p 1/15 g/l	2,5 V_p
EOR-4	1 V_p	1 V_p	0,25 V_p 0,5/20; 0,25 V_p 0,25 g/l; 0,25 V_p 0,5/10 g/l; 0,25 V_p 0,25 g/l	2,5 V_p
EOR-5	1 V_p	1 V_p	0,25 V_p 0,5/20; 0,25 V_p 0,25 g/l; 0,25 V_p 0,5/15 g/l; 0,25 V_p 0,25 g/l; 0,25 V_p 0,5/10 g/l; 0,25 V_p 0,25 g/l	2,25 V_p

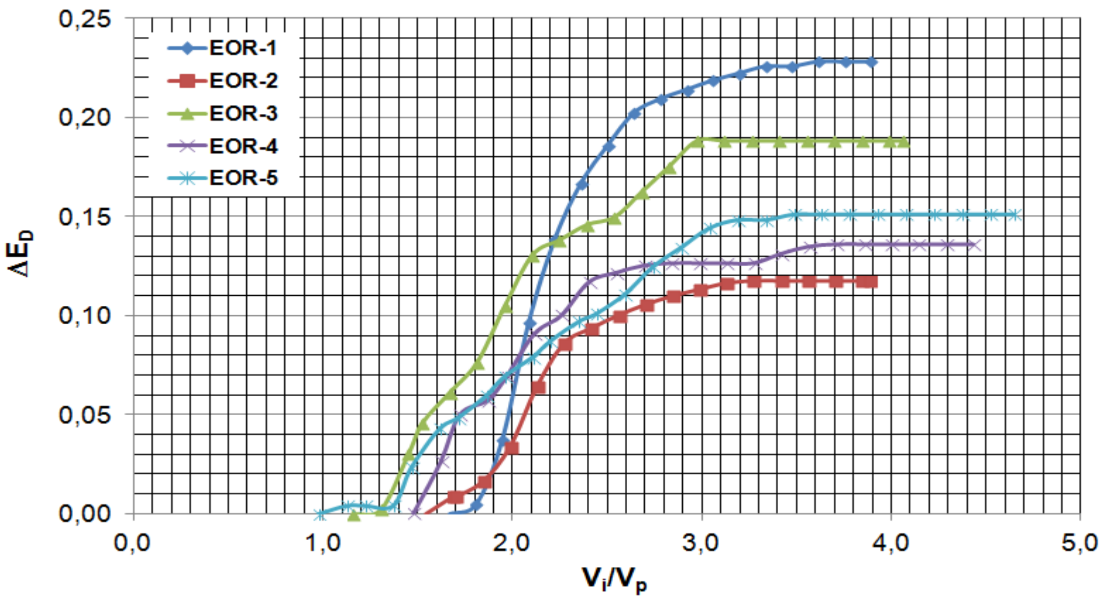
CONCLUSION

From the recorded displacement volumes drops in oil saturations can be calculated and therefore the increase in displacement efficiency. The enhanced production is presented as the difference of oil productions gained by water displacement and additional polymer-tenside followed by following water injections. The value of ΔE_D is consists of two parts, one recorded at the slug and the other gained at the injection of the following water. The values of the calculated ΔE_D are listed in ***Table 4*** and presented in ***Graph 3***.

As it can be seen best production was reached at measurement number ***EOR-1*** where the scenario was that polymer-tenside slug had volume equal to 1 V_p and following water had volume of 2 V_p. At measurement number ***EOR-3*** decrease can be clearly seen in production due to lesser slug volume and an even greater decrease was recorded at measurement number ***EOR-2***. Which could be an anomaly, because basis would have shown that productions at the second measurement should have been higher, than in case of the third as result of decreased polymer and tenside volumes. This could be caused of some kind of plugging inside of its pore system, that could be related to some sort of clay content or the polymer could not reach the pores desired for additional oil production.

Table 4
Additional oil productions recorded

Sample	Displacement Eff., %	Enhanced D. Eff., %	Additional D., %
EOR-1	54,12	76,94	22,82
EOR-2	61,96	73,70	11,74
EOR-3	66,67	85,52	18,85
EOR-4	61,90	75,47	13,57
EOR-5	68,06	83,20	15,13



Graph 3
Additional Displacement efficiencies

From measurements number ***EOR-4*** and ***EOR-5*** it can be clearly seen that procedures applying multiple slugs were not as beneficial as if only a single slug was being used, also they were much more harder to proceed due to the difficultness of multiple injection phases and higher pressure differences recorded throughout their entire procedures.

This leads to the conclusion that:

1. From the measurements it can be stated that 1 slug injections are preferable to multiple slug injections.
2. Best increase in oil production was achieved at 1 V_p volume slug size.
3. Small changes were recorded even at much smaller slug volumes (half of V_p decrease resulted only 4% difference in ΔE_D).

As for polymer-tenside slug injections from the measurements it can be said that the most preferable scenario for sandstone reservoirs with similar petrophysical properties is the application of 1 single slug with volume of 0,5 V_p displaced by 2,5 V_p following water.

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