A NEW VISION OF POLYMER FLOODING AS METHOD OF HIGH-VISCOUS OIL DISPLACEMENT

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ABSTRACT: Development of Oil Field with oil viscosity of 30 cP and above usually associated with the use of methods of enhanced oil recovery (EOR), requiring significant investment in oil field equipping and development organization. This paper focuses on polymer flooding as one of the ways of EOR to displace high-viscosity oil. It is shown that the area of application of polymer solutions has grown significantly, and now polymer solutions effectively displaced oil with a viscosity of hundreds and thousands of cPs. Thus the required viscosity, and hence the concentration of the polymer solution is much lower than in conventional approaches, which significantly improves the attractiveness of the investment in the displacement method of high-viscosity oils.

The mobility of high-viscosity oil is low, it greatly limits the production rate of wells, and, consequently, high-viscosity oil containing fields recovery factor. Traditional methods of enhanced oil recovery (EOR) for the fields of this oil base on the reduction of the oil viscosity and increase oil mobility using thermal methods. In some cases, such as deep-seated or thin-layers, thermal methods cannot show good results.

According to many experts, polymer flooding is the most widely used method among chemical EOR. By adding the polymers, the mobility of water and oil ratio is reduced, leading to greater efficiency of the process of oil production. It is believed that polymer flooding can significantly reduce the residual oil saturation, but using polymer flooding can achieve it in a shorter time.

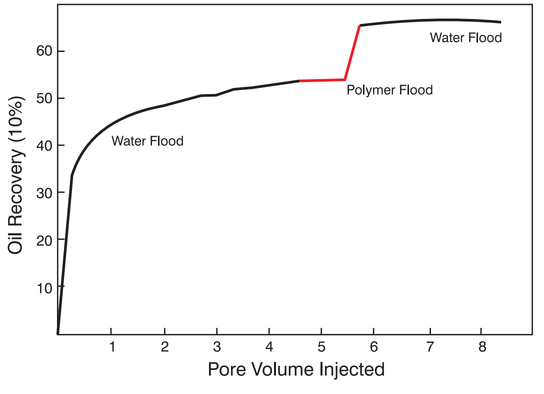

Fig. 1. Oil Recovery with waterflooding followed by polymer flooding [1]

This method is used as a secondary method, and very often, a tertiary oil recovery method after mature fields waterflooding, even when the water cut is 90% or higher. This is well illustrated by C.H. Gao [1].

Despite considerable accumulated experience in the application of polymer flooding program continues in its research and refinement. Actively studied issues to reduce costs, improve displacement efficiency, and reduce application time, application extension.

Table 1 lists some of the traditionally accepted criteria for the selection of sites for polymer flooding. It is evident that these criteria are very different, as the accumulation of differences grounded field experience and progress in the development of polymer compositions used for polymer flooding.

Table 1. Screening criteria for polymer flooding

Variable	Carcoana (1982)	Taber (1997)
Depth [m]	< 2000	< 2743
Permeability [mD]	> 50	> 10
Oil viscosity [sP]	50÷80	10÷100
Oil density [kg/m^3]	NR	< 0.966
Oil saturation [%]	> 50	> 50
Temperature [°C]	< 82	< 93

At the present time, the accumulation of knowledge, the development of new polymer compositions, revaluation of parameters of polymer flooding rationality, polymer flooding technology is becoming economically viable in the development of reservoirs with oil viscosity greater than the criteria stated above.

Table 2 shows the criteria for applicability of polymer flooding in recent years, which clearly shows the displacement possibilities of application of this method in the direction of displacement of oil still higher viscosity [3].

Table 2. Current screening criteria for polymer flooding in relation to the displacement of heavy oil [3]

Variable	Al-Adasani and Bai (2010)	Dickson and others (2010)	Saboorian-Jooybari (2015)
Depth [m]	213÷2883	243÷2743	1600
Porosity [%]	Not Reported (NR)		21
Permeability [mD]	1.8÷5500	> 100, if μ < 100 sP > 1000, if μ < 1000 sP	> 1000
Oil viscosity [sP]	0.4÷4000	10÷1000	< 5400
Oil density [kg/m^3]	0.813÷0.979	< 0.966	< 0.993
Oil saturation [%]	34÷82	> 30	> 50
Temperature [°C]	< 114	< 77	65
Salinity [ppm]	Not Reported (NR)		< 46000
Oil mobility [mD/sP]	Not Reported (NR)		> 0.31
Oil/polymer viscosity ratio	Not Reported (NR)		< 279

Figure 2 shows that the criteria for the applicability of polymer technologies have improved markedly [4].

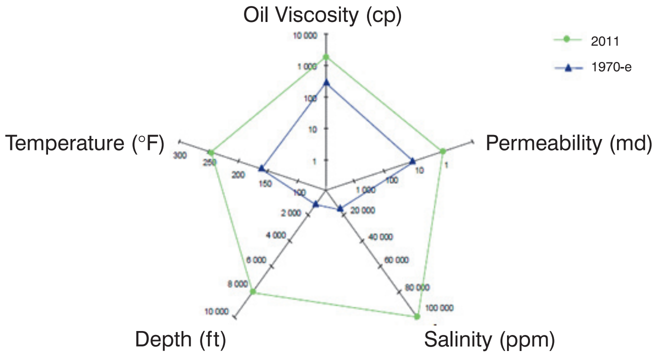

Fig. 2. The evolution of polymer technology [4]

Currently, polymer flooding is used in oil viscosity to several thousand centipoise (mPa · s), with a minimum permeability of at which applied polymer flooding is 0.001 μm^2 (md) and the corresponding reservoir temperature reaches 121°C (250°F). Also increased demand for water salinity used for polymer flooding, up to 100,000 ppm (10%), and the application reaches a depth of 2500 or even 2900 m.

The efficiency of polymer flooding projects varies widely. Previous successful polymer flooding estimated between 5 and 30% of additional oil (Zhu et al. (2012)) [7]. China reported growth of Oil Recovery Factor in the range of 7 to 15% with polymer flooding. Mogollon and Lokhandwala (2013) received an additional ORF from 5 to 15%, while the water cut decreased to about 50%. Chevron Group has built a database on the basis of published data, which shows the polymer experiments and projects at the deposits with collectors – sandstones around the world (about 68). They included only successful projects where additional ORF was between 5% and above. Unlike Chevron, SRC included unsuccessful projects to identify the parameters that affect the success or failure of projects.

Table 3 presents the main characteristics of layers, which is carried polymer flooding. Table 4 shows the results of different methods of polymer flooding in the fields of heavy oil in Canada.

Table 3. Characteristics of selected projects [6]

Projects	Pelican Lake	Mooney	Seal
Company	CNRL and Cenovus	Black Pearl	Murphy
Type	PF	PF & ASP	PF
Formation	Wabiskaw	Bluesky	Bluesky
Average depth [m]	300÷450	900÷950	610
Average net pay [m]	5	2.5	8.5
Porosity [%]	28÷32	30	27÷33
Permeability [mD]	300÷5000	100÷10000+	300÷5800
Water saturation [%]	30÷40	30	20÷35
Reservoir temperature [°C]	12÷17	29	20

Table 3. cont.

Projects	Pelican Lake	Mooney	Seal
Initial reservoir pressure [MPa]	1.8÷2.6	5.8	5.15
Density [kg/m^3]	0.972÷0.986	0.940÷0.986	0.986÷1.000
Formation volume factor [m^3/m^3]	1.006	1.052	1.02
Solution gas/oil ratio [m^3/m^3]	4÷6	17.5	9.9
Dead oil viscosity [cP]	800.80000	300÷500	5000÷12000
Live oil viscosity [cP]	800.80000	120÷300	3000÷7000
OOIP, MMbbl	6500		

Table 4. Recent polymer EOR Field cases in Canada [6]

Company	Field	Pool	Province	Dead oil viscosity [Pa · s]	Status
CNRL	Pelican Lake	Wabiskaw	AB*	1.5÷2.5	Full field
Cenovus	Pelican Lake	Wabiskaw	AB	1.5÷2.5	Full field
Pengrowth	East Bodo	Lloydminster	AB/SK*	1.1	Severe operational issues
Pengrowth	Cactus Lake	MacLaren	AB/SK		In progress
Murphy	Seal	Bluesky	AB	5÷12	Positive response
Black Pearl	Mooney	Bluesky	AB	0.255÷0.4	Successful polymer pilot, ASP appears successful
Nexen	Court	Bakken	SK	0.860	Failure
Enerplus	Giltedge	Lloydminster	AB	0.8÷1.2	Early polymer BT
Enerplus	Medicine Hat	Glauconitic	AB	1÷1.5	Starting
Enerplus	Wildmere	Lloyd A and Sparky E	AB	0.7	In progress
Northern Blizzard	Cactus Lake	Basal Mannville-Bakken	SK		?
Harvest	Suffield	Caen	AB	0.4÷0.6	Successful
Harvest	Wainwright	Sparky	AB	0.1	?
EnCana	Viking Kinsella	Sparky	AB	0.1	?

AB – Alberta, SK – Saskatchewan

Table 5 compares the viscosity of oil and the polymer solution. The viscosity of solutions pumped in the same range is practically independent of the oil viscosity. Typically, the polymer viscosity for fields with low viscosity oil is selected considering mobility ratio. However, this approach to high-viscosity oil is not possible, as this will lead to ultra-high viscosity of the solution, which will significantly reduce the system injectivity with extraviscous solution falling into the reservoir. Thus, it is necessary to observe the balance between improving the mobility ratio and maintaining the injection rate of the level.

Table 5. Comparison between oil and injected solution viscosity [6]

Reservoir	Oil viscosity [cP]		Viscosity of injected solution [cP]
	dead	live	
Pelican Lake (pilot)	1200÷1800	1500	13÷25
Mooney	300÷500	120÷500	20÷30
Seal	5000÷12000	3000÷7000	25÷45
Taber	120	50	22÷32
Suffield	480	180÷250	22

Wang and Dong (2007–2009) had a large number of tests to study the potential of polymer flooding in the fields of high-viscosity oil and the time required to start flooding [8, 9]. There have been several reports, the most important of which is that there is a certain range of viscosity of the polymer solution (on the so-called S-curve), in between which the ORF growth increases significantly with an increase in the viscosity of the polymer solution (Fig. 3). On the other hand, when the polymer solution viscosity outside this range little gain. They also determined that the S-shaped curve is shifted towards lower viscosity solution of residual oil in large quantities. This means that it will take a smaller concentration of the polymer solution, polymer flooding, if applied in the early stages of development of the deposit.

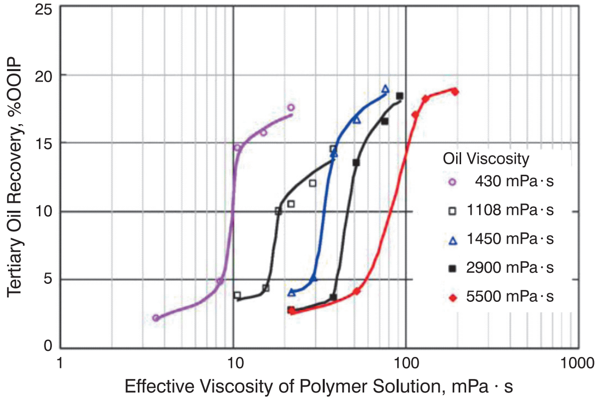

Fig. 3. S-shaped curves of Wang & Dong [4]

The author analyzed and presented by Wang & Dong S-shaped curves on the basis of which was built by the express-method of selection of the effective viscosity of the polymer solution, necessary for the effective heavy oil displacement.

The sequence of required actions as follows:

1. Have been identified upper turning point of S-shaped curves, corresponding to the value of the effective viscosity of the polymer solution for each experiment oil.
2. Was the dependence of the effective viscosity of the polymer solution on the viscosity of the displaced oil:
   $\mu_Э = 0{,}02 \cdot \mu_H + 8{,}265$
   where $\mu_Э$ and μ_H – the effective viscosity of the polymer solution and the viscosity of displaced oil, cP.

3. Built trend, allowing to estimate the expected recovery factor increase with polymer flooding, held after the traditional flooding:

   $\Delta ORF = -0{,}0001 \cdot \mu_Э^2 + 0{,}0407 \cdot \mu_Э + 14{,}572,$

   where $\mu_Э$ – the effective viscosity of the polymer solution.

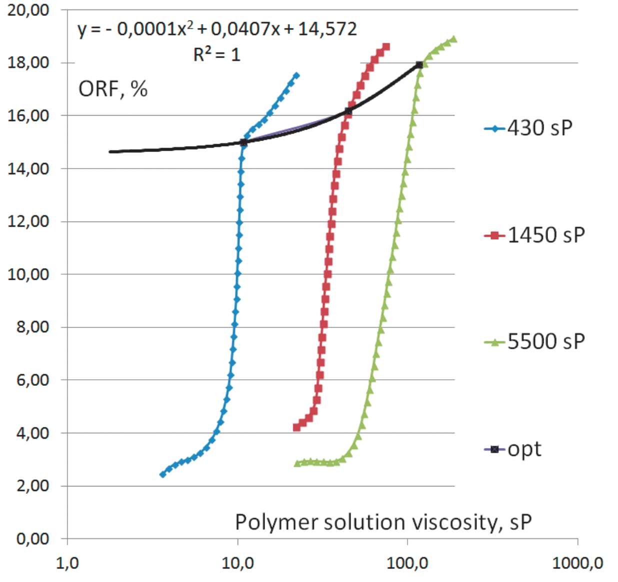

Fig. 4. Processing of the family of S-shaped curves

The viscosity of polymer solutions has been restated on the basis of the proposed algorithm for deposits from Table 5, as well as other high-viscosity oil deposits (see Table 6).

Table 6. Comparison between oil and injected solution viscosity with the new express methods

Reservoir	Viscosity of live oil [cP]	Viscosity of injected solution [cP]	Effective viscosity of injected solution [cP]
Pelican Lake (pilot)	1500	13÷25	38.4
Mooney	120÷500	20÷30	10.7÷18.3
Seal	3000÷7000	25÷45	68.5÷148.7
Taber	50	22÷32	9.3
Suffield	180÷250	22	8.3
Oudeh	470		17.7
Saida & Zarba	42		9.1
Karajida	38,9		9.0

The above calculated data shows that for the high-viscous oils polymer concentration used is excessive, the viscosity of the polymer solution must be substantially adjusted for high-viscosity oils.

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Новое видение полимерного заводнения как метода вытеснения высоковязкой нефти

СОДЕРЖАНИЕ: Разработка месторождений с вязкостью нефти более 30 сП, как правило, связана с применением методов увеличения нефтеотдачи (МУН), требующих значительных инвестиций в обустройство промыслов и организацию добычи. В этой работе основное внимание уделяется полимерному заводнению как одному из способов МУН для вытеснения высоковязких нефтей. Показано, что область применения полимерных растворов значительно расширилась, теперь полимерными растворами эффективно вытесняется нефть с вязкостью сотни и тысячи сантипуаз. При этом необходимая вязкость, а, следовательно, и концентрация полимерного раствора значительно ниже, чем при традиционных подходах, что значительно улучшает инвестиционную привлекательность метода при вытеснении высоковязких нефтей.

Recenzent:
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