POLYMER FLOODING PROCESS TO INCREASE RECOVERY FACTOR

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This paper describes a methodology, developed at the Instituto Colombiano del Petróleo (Colombian Petroleum Institute) of Ecopetrol, for the theoretical evaluation, project design (screening, geological and engineering analysis, experimental evaluation, numerical simulation and financial analysis), pilot implementation and surveillance of the polymer flooding process which is a commercial Enhanced Oil Recovery (EOR) technology. Its principal objective is to improve reservoir sweep efficiency in mature and recent waterfloods.

The polymer flooding pilot test implemented in the south of Colombia by Ecopetrol includes two injector wells with irregular patterns. Polymer injection started in May 2015. At October 2016, cumulative polymer injection reached 1.5 million barrels distributed between both injectors at a polymer concentration range between 200-1500 ppm and injection rates between 2 000-3 200 BPD per pattern.

Production initial response has been positive with a cumulative incremental that exceeds the 63 000 barrels of oil with reduction of water cuts of up to 10 %. Additionally, polymer production has not been detected in any of the offset producers of pilot injectors. The polymer flooding pilot test have allowed the assimilation of learned lessons, best practices for continual improvement in the operation of such processes, incremental oil production; water cut reduction and increases in the fluid levels for the first row of offset producers. Based on the pilot success, the feasibility of expanding this EOR method in this field is being evaluated.

Keywords: Enhanced oil recovery (EOR), polymer flooding, experimental feasibility, numerical simulation, polymer flooding facilities

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1. Introduction

Use of polymer solutions to improve volumetric sweep efficiency based on a reduction of mobility ratios in waterflooding processes has become a standardized practice in the operation of different oil fields. Mungan, Smith and Thompson (1966) conclude that mobility of polymer solutions is affected by several factors such as the polymer concentration, type and size of molecule, water salinity, pH, capillary properties of the rock and crude oil type. The polymer flooding process is more effective in cases of heterogeneous fields containing moderate-viscosity crude oil. However, Mogollón and Lokhandwala (2013) provided evidences of good results in high-viscosity crude oil reservoirs.

The average recovery factor in Colombia is approximately 19 %, and about 90 % of the oil fields of the country are still producing at their primary stage. About 88 % of production comes from primary recovery, 11 % of secondary recovery and less than 1 % of production come from enhanced oil recovery (Castro et al., 2010). Different enhanced oil recovery pilots have been implemented as alternatives to increase oil production and maximize final recovery in Colombian fields.

This paper discusses the strategy, protocols and methodology used to design, implement and monitoring a polymer flooding project. It presents as an application case the stages of screening, area selection, experimental feasibility, numerical simulation, infrastructure, automation, execution and online monitoring of the polymer flooding pilot project.

In the experimental study, the selection of polymers was based on the following parameters: compatibility and solubility with the formation water, viscosity of the polymer as a function of concentration and shear stress, viscoelasticity (screen factor), filterability and rheological behavior studies. Even though the test protocols used were mainly based on the API RP63 standard (1990), other methods for selection of products (Levitt, Pope, 2008; Seright, Seheult, Talashek, 2008; Sorbie, 1991) were also considered. The technical and experimental evaluation process identified one company to supply and inject the selected polymer.

Execution of the pilot project started in May 2015. The injection facilities (single well type) used have allowed the displacement of more than 1.5 million barrels of polymer solution to the reservoir. Some results of this project are a decrease in water production and an increase in oil production and final expected recovery factor.

2. State of the art

The use of polymers in enhanced oil recovery processes dates back to the beginning of the 60s. Ever since, a high number of field tests have been reported in literature with a higher number of successful cases around the world since the 80s, especially in China, where oil production is significant thanks to CEOR processes (Weiss, Baldwin, 1985; Putz, Lecourtier, Bruckert, 1988; Putz, Rivenq, 1992; Delamaide, Corlay, Wang, 1994; Han, 1999; Du, Guan, 2004; Chang et al., 2006; Li et al., 2009; Wang et al., 2009; Zhang et al., 2016) and recently in projects developed in Canada, Oman, Surinam, Colombia, among others (Manrique et al., 2010; Buciak, Fondevila, Del Pozo, 2013; Standnes, Skjevrak, 2014; Maya et al., 2015 b).

Two types of polymers have been used for field applications: polysaccharides and polyacrylamides, being the partially hydrolyzed polyacrylamide (HPAM) the most widely used polymer in EOR applications (Manrique, Muci, Gurfinkel, 2007). In fresh water, due to charge repulsion of the carboxylic group, the flexible chains of the HPAM structure stretch raising the viscosity of the solution. In contrast, in high salinity water charges are neutralized or covered and the flexible chains of the HPAM structure are compressed resulting in solutions with lower viscosity (Sheng, 2011).

Some researchers concluded that polymer flooding may reduce relative permeability of the aqueous phase (Barreau et al., 1999; Zheng et al., 2000; Grattoni et al., 2004). On other part, Huh and Pope (2008) observed that residual oil saturation is lower after a polymer flooding process than after an analogous waterflooding process.

Interaction of the aforementioned parameters makes the flow of polymer solutions in porous media a very complex process. Additionally, uncertainties associated to reservoir characterization make the design and implementation of a robust polymer flooding project a challenge. A poor design and implementation of a polymer flooding project may even cause a reduction in oil production; thus, authors as Yuan (2009) highlight the importance of a representative numerical simulation before the polymer injection in the field as an essential step to be successful in the design and implementation.

3. Field case implementation and analisys

Implementation of recovery technologies is essential to increase the recovery factor in Colombian oil fields. In order to reach the production and reserve goals of the Company, Ecopetrol started an aggressive plan for implementation of waterflooding combined with the optimization in progress of such fields using conformance technologies and assessment of different EOR technologies as the injection of colloidal dispersion gels, polymers and surfactants (Castro et al., 2010; Castro-García et al., 2013 a; Castro et al., 2013 b; Castro et al., 2014; Maya et al., 2012; Maya et al., 2014; Maya et al, 2015 a; Maya et al., 2015 b; León et al., 2015).

Accordingly, the Instituto Colombiano del Petróleo (Colombian Petroleum Institute, ICP) of Ecopetrol developed an integrated methodology from the preliminary assessment to the field implementation at pilot scale including monitoring strategies of the polymer flooding process with the purpose of providing guidelines for the design, execution and optimization of this enhanced oil recovery process. This section summarizes the methodological analysis of the main stages executed in the pilot project of polymer flooding in Palogrande-Cebú Field, which was developed and implemented following the methodology created at ICP (Maya et al., 2015 b). According to the technical screening, the field characteristics are appropriate to implement polymer and surfactant-polymer flooding technologies as enhanced recovery methods.

Assessment and selection of pilot areas

As initial input, a detailed data gathering and analysis is required to assess the static and dynamic information of the reservoir. The review of every wellbore configuration status and of the injection/production history also represents a critical step to identify, rank and select potential areas for polymer flooding implementation. Basically, an area must have enough recoverable oil, hydraulic connectivity between injection and production wells active flooding patterns and, preferably, the sector must be confined to be selected (Castro et al., 2013 a).

The mobility ratio of Palogrande-Cebú Field during the waterflooding process has an approximate value of 7.5, indicating low efficiency of the secondary recovery process. The oil recovery factor is 27 %.

Selection of the area for the implementation of the polymer flooding pilot project was based mainly on the geological (e.g. stratigraphic correlations, petrophysical properties, determination of permeability variation coefficient, hydraulic connectivity between wells, etc.) and engineering analysis (e.g. historical analysis of injection/production, injection records, fracture pressure, etc.).

According to the methodology, the waterflooding process was reviewed to make technical and conceptual analyses.

Once the sector was chosen as the area with the best conditions to implement the pilot test, a detailed analysis for each well was developed in order to select the most appropriate pattern for polymer flooding. The patterns PG-34 and PG-37 were the best options to evaluate this technology (Figure 1).

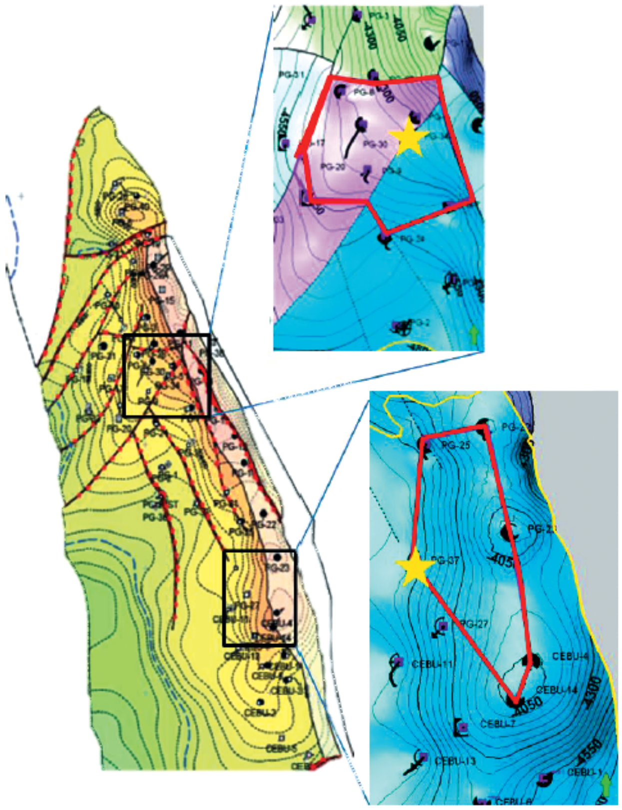

Figure 1. Patterns (PG-34 & PG-37) selected for the polymer flooding pilot project.

Experimental evaluation

The experimental evaluation was developed in accordance with the recommended practices for assessment of polymers used in enhanced oil recovery operations (API RP63). Basically, the behavior of viscosity of polymers at different concentrations and conditions was evaluated; filterability and rheological studies (mechanical degradation tests are conducted considering the wellbore conditions and the surface facilities). Finally, the thermal and chemical degradation are evaluated at reservoir conditions using the preparation water (field and synthetic) of the polymer solution (Figure 2).

Once polymer flooding was identified as the appropriate EOR technology to increase the oil recovery factor in Palogrande-Cebú field, the experimental study was developed to determine compatibility between HPAM polymers type and the reservoir rock / fluids, to estimate the optimal polymer concentration (required to reach the targeted viscosity value) and evaluate the mechanical, thermal and chemical stability of the polymer solution.

Through a market intelligence process, eight companies with experience supplying polymers and operating EOR projects were identified. In total, 13 polymers were evaluated and characterized in order to choose the products that shall have the best performance. Two polymers were discarded because they not were soluble in the water brine. All the polymer solutions evaluated were compatible with the reservoir fluids showing full phases separation and without evidencing emulsions in the aqueous phase.

To this project was decided to use water from the field injection plant an optionally, water from aquifer to prepare the polymer solutions for the pilot test. It is important to highlight that the water coming from the aquifer has very low salinity and hardness, with no content of iron or dissolved oxygen and is compatible with the reservoir rock and its fluids. In the reservoir conditions for all polymer solutions, the target viscosity

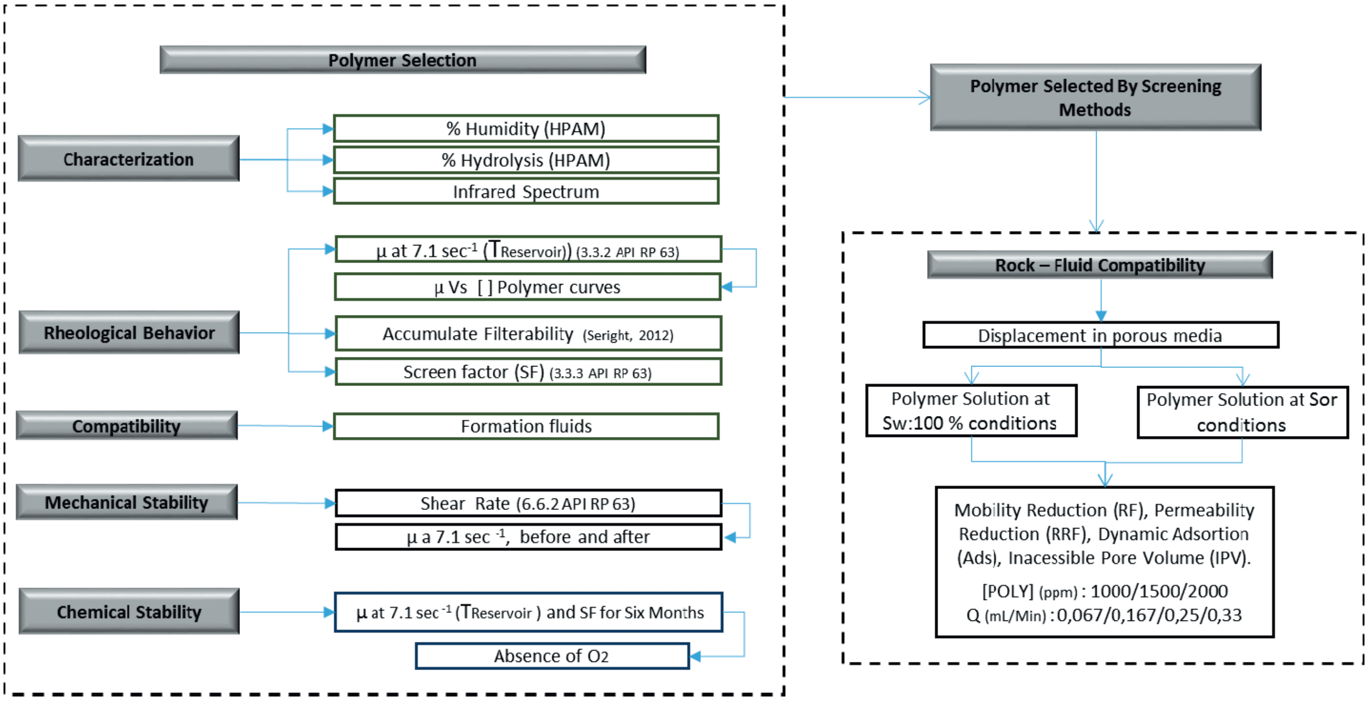

Figure 2. Selection and assessment of API RP63 polymer.

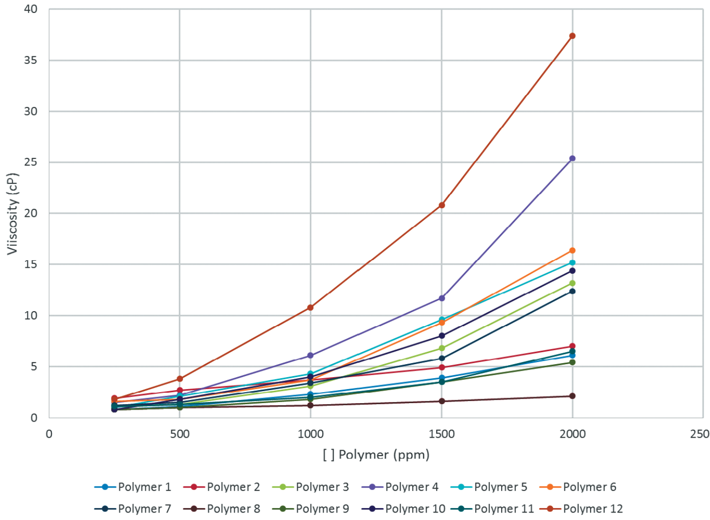

Figure 3. Polymer Viscosity vs. polymer concentration at 7.1 s^{-1} (62°C).

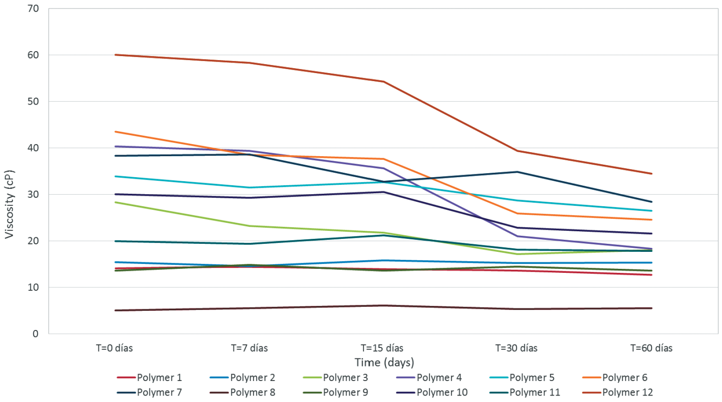

Figure 4. Chemical and Thermal Stability – Viscosity vs. Time at 7.1 s^{-1} (62°C).

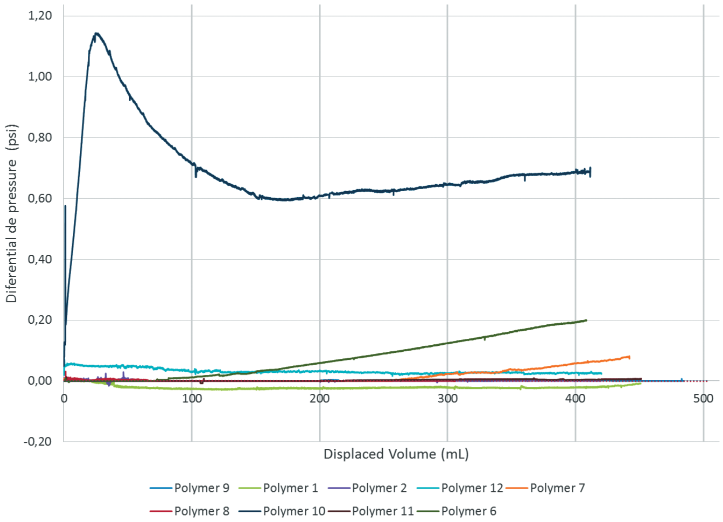

Figure 5. Accumulate filterability for polymer solutions at 1000 mg/L.

was obtained in acceptable concentration ranges (Figure 3). Thermal and chemical degradation tests showed that reservoir and water composition affect significantly (>25 % of loss viscosity) the viscosity of five of polymer solutions evaluated over time (Figure 4).

Additionally, considering the Accumulate filterability test as a very important parameter, one polymer assessed was dismissed since it caused plugging problems (Figure 5). Then, shear rates of up to 50 000 s^{-1} were applied to the polymer solutions in order to assess their mechanical degradation, simulating the potential shear effects caused from the pumps of the injection facilities to the perforations of the injection wells. Under these conditions, most of the polymers showed viscosity losses higher than 30 % (Figure 6).

Finally, based on the results of the viscosity, accumulate filterability and Thermal-Chemical and mechanical stability tests, polymers 8 and 9 approved all of them and were chosen to used in the project. The results were considered to determine the optimal concentration to be used in the polymer flooding pilot. A polymer concentration of 1500 ppm was determined to generate the target viscosity in water reservoir and 700 ppm in aquifer water at reservoir temperature.

Once polymers were properly evaluated at fluid/fluid level, linear displacement tests (coreflooding) were conducted using the selected polymer products in order to evaluate the main rock-fluid interaction parameters. The polymer adsorption was estimated in 39 µg/g of rock under irreducible oil saturation to water (S_{orw}), which is considered a low polymer adsorption.

The inaccessible pore volume (IPV) was estimated approximately in 16 %. This result is within the expected value for this type of polymers of low molecular weight (5-10 million Daltons) and the petrophysical properties of Palogrande-Cebú reservoir rock. The low polymer adsorption and IPV values are promising and suggest that polymer solution shall have a good viscoelastic and flow behavior in the reservoir. Aditionally, mobility reduction (RF) was estimated in 5.9 and permeability reduction (RRF) in 1.3 by coreflooding test injecting polymer solution at 1500 ppm in residual oil saturation conditions.

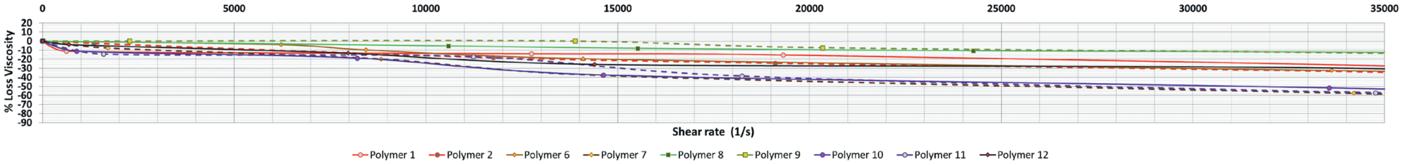

Figure 6. Mechanical degradation for sheer strength in polymers at 1000 ppm concentration (59°C).

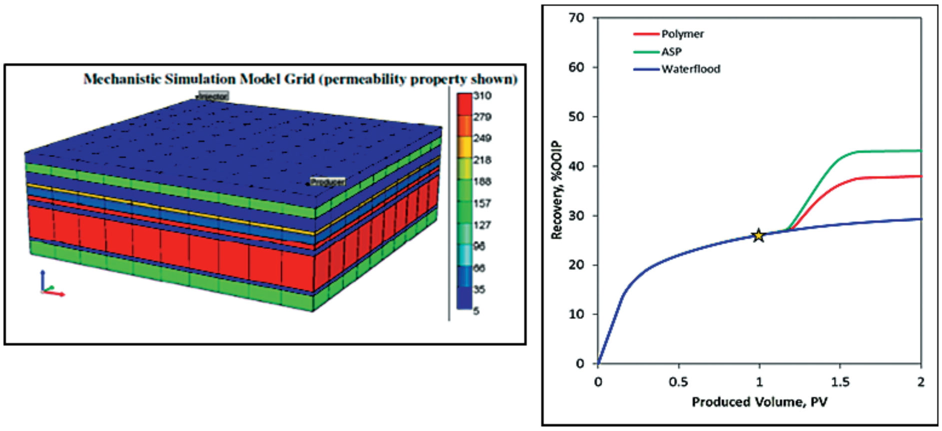

Figure 7. Mechanistic simulation model for Palogrande-Cebu field.

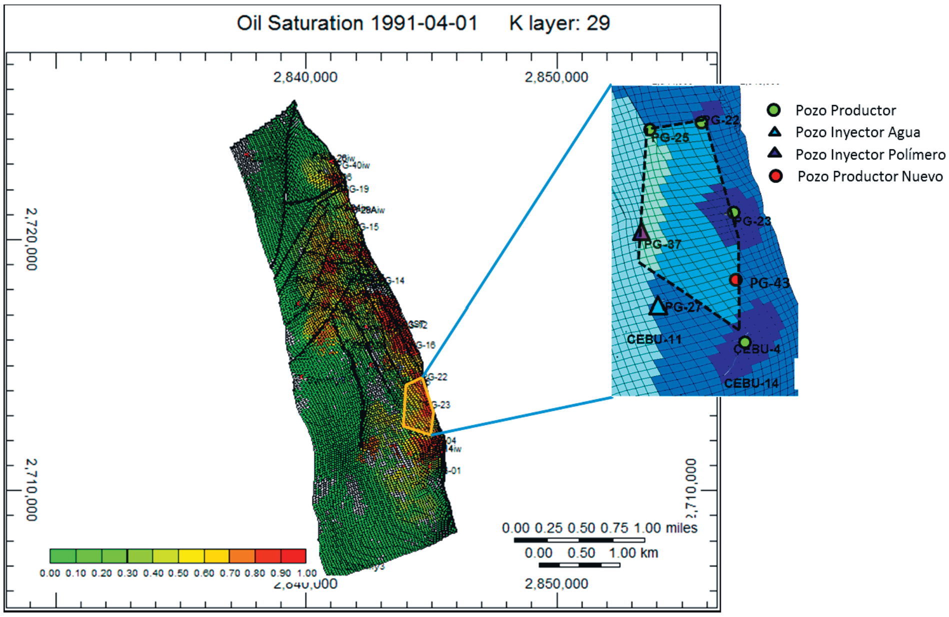

Figure 8. Field Model with pilot pattern PG-34, Palogrande-Cebú Field.

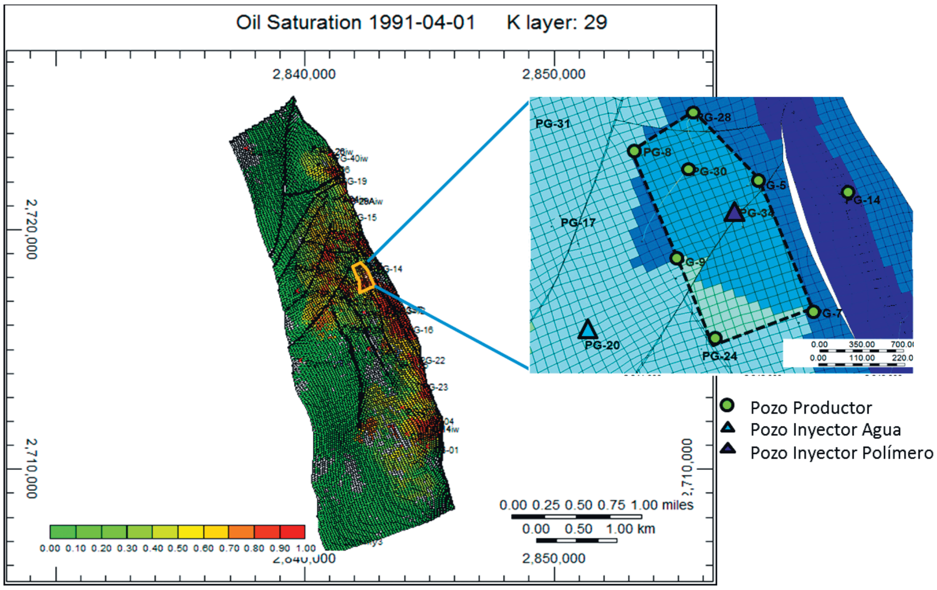

Figure 9. Field Model with pilot pattern PG-37, Palogrande-Cebú Field.

Numerical simulation and process design

Numerical simulation supports the design of the polymer flooding process since it helps to define the percentage of porous volume to be injected, operating conditions of the process, and estimated capacity of the surface facilities and different injection scenarios that may be assessed technically and economically.Numerical simulation is generally developed in commercial software (i.e. CMG STARS®).

Initially the numerical evaluation involves the construction of mechanistic simulation model using fluid (PVT) and reservoir data from the field and history matching. This model were used to evaluate different scenarios of injection from two different chemical EOR process: ASP and PF.

The results shows in terms of oil recovery a good response for both ASP and PF, achieving the oil production an incremental values of recovery between 8 to 20 % of OOIP (Figure 7).

Figure 8 and Figure 9 show the model used for the simulation of polymer injection for both patterns at field level. After history matching of the numerical model, different polymer flooding scenarios were evaluated. This analysis allowed identifying the performance of the pilot project under different injections schemes and operating conditions.

The behavior of the polymer solution is typically represented by four parameters. The first one is the dynamic adsorption, retention and/or trapping and its propagation in the reservoir rock. The second one corresponds to the inaccessible pore volume (IPV) that is important to model the porous fraction of the rock in which the polymer solution would not penetrate. The third one corresponds to the viscosity of the polymer solution and the sheer rates which are directly related to mobility reduction (RF) and the last one is the reduction of permeability in the reservoir after the polymer flooding process (RRF). The experimental evaluation generated key information required as input parameters for the numerical simulation of polymer flooding.

Figure 10 shows the oil recovery factor forecasted in the sector modeled for different injection scenarios of polymer solution in both well patterns (PG-34 and PG-37). The oil production shows an incremental of more than 300 BOPD (blue line) compared to waterflooding (red line) at the same operating conditions.

Based on a cost – benefit ratio, the best scenario identified during the simulation study was injecting a total of 0.2 pore volumes (PV) of polymer solution in each well pattern, using an average injection rate of 2 000 BPD (per pattern) and a polymer concentration of 1500 ppm. For all scenarios, after the injection of 0.2 PV of polymer slug, water injection was forecasted until 2040. Oil production response ranged between 12 and 16 months for the different scenarios evaluated.

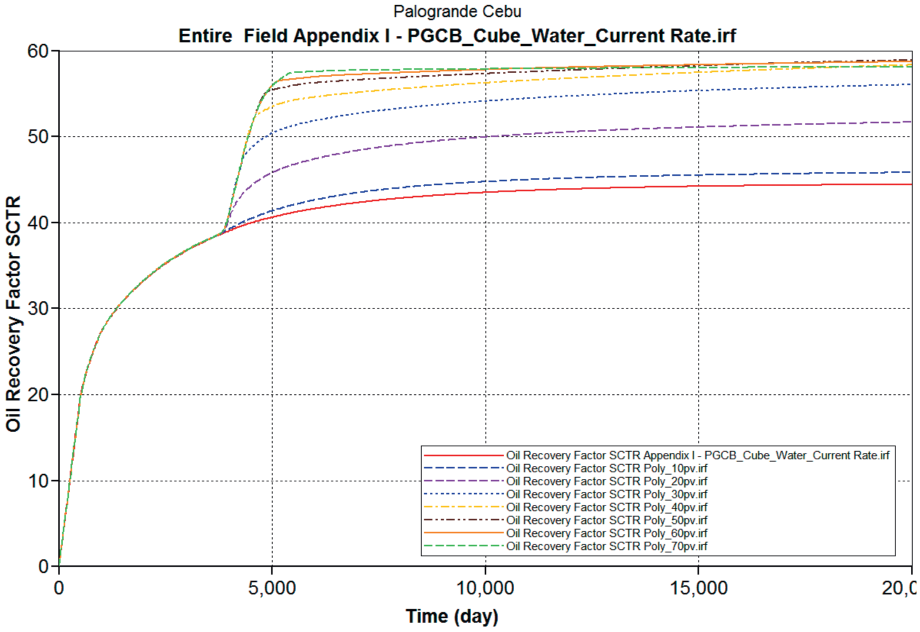

Figure 10. Simulation scenarios for polymer flooding vs. waterflooding.

Figure 11. Polymer flooding pilot facilities in the injection wells.

Forecasts showed a cumulative incremental production of 480 000 oil barrels (bbls) and 482 000 bbls in offset producer well patterns PG-34 and PG-37, respectively. Additionally, the model also predicts an important decrease on the water cut.

With the purpose of determining the financial feasibility of the project, economic evaluations were performed in order to support the management decision-making process for the polymer flood pilot. Project economics presented positive results suggesting that polymer flooding technology is promising showing representative incremental production with regards the total cost of the pilot project.

The analysis of the simulation results were used to select the best strategy for the execution of the pilot project and to support the polymer flooding and injection facilities design.

Injection facilities for the pilot project

The polymer flooding facility usually is designed as a functional unit in a closed cycle of blending, dilution, pumping and final injection in the well with the goal of avoiding undesired losses and leaks in the process, as well as guaranteeing the quality and effectiveness of such process.

Surface facilities include water storage, power system and injection unit equipped with a solid polymer dosing system, blending and tanks for maturing, hydration and activation of the polymer, positive displacement pumps for injection and a nitrogen flow system in the entire unit to displace the oxygen avoiding polymer degradation.

The execution of this polymer flooding pilot project was decided to run two parallel flooding patterns in wells PG-34 and PG-37. For the modular injection unit installation, mechanical, civil, electric works and an area of approximately 2000 m^2 was required (Figure 11).

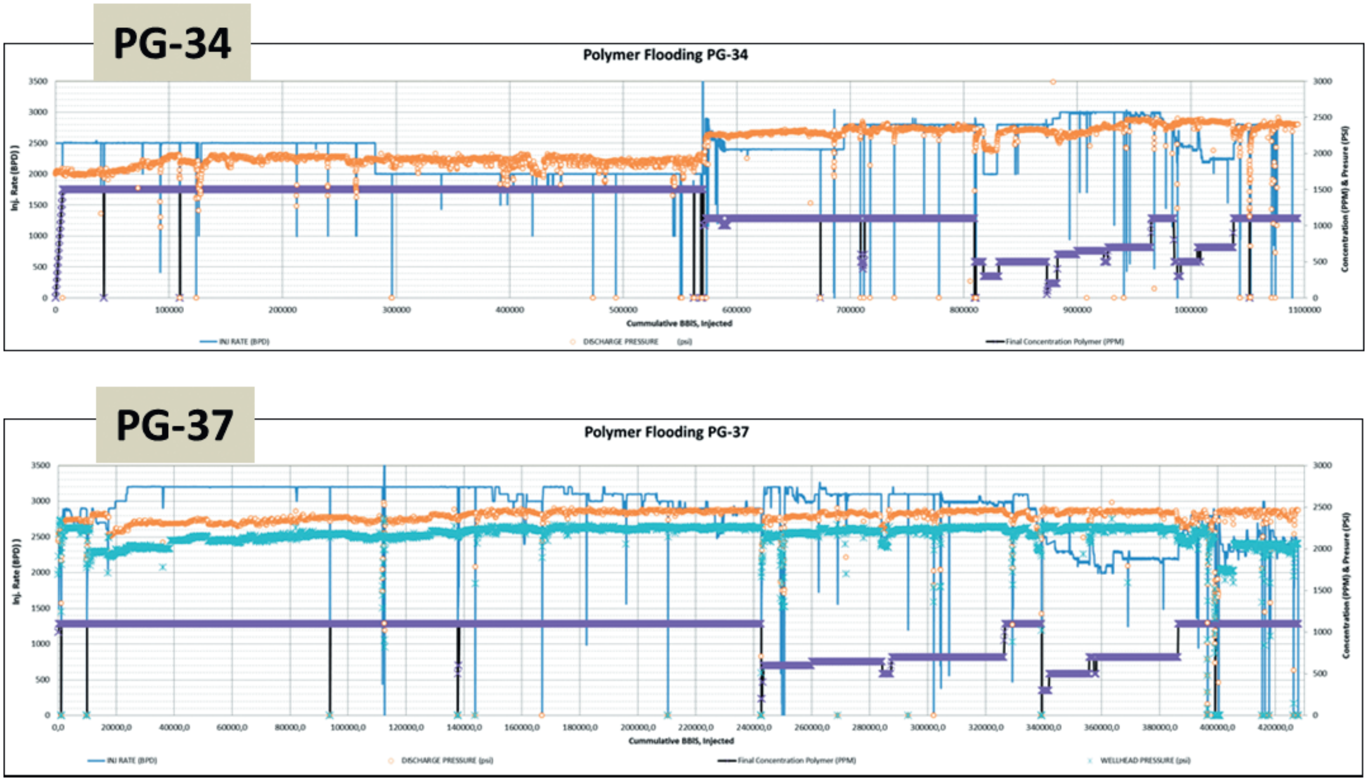

Figure 12. Behavior of flooding of patterns PG-34 and PG-37.

Process execution and monitoring of pilot project

The polymer flooding pilot project started in May 2015 in well PG-34 and nine months later in well PG-37. The main goal of this pilot project is to collect as much information as possible to understand the performance of this polymer flood to validate the technical and economic feasibility of the technology and assess, thus, its potential for a possible expansion to the entire field. As shown in Figure 12, because of different evaluations and operational issues, injection rates and the concentration of polymer were modified along the injection without exceeding the operating pressure limit.

During the execution of the pilot project, a permanent monitoring has been conducted to control polymer concentration and verify that the target viscosity was reached in the reservoir. Daily measurements of viscosity and filterability, and basic tests of injection water quality, as well as monthly tests of basic properties of the polymer lot used (humidity and hydrolysis) were made. Additionally, monitoring of the influenced producer wells in order to evaluate the produced fluids. During the pilot execution, no polymer production has been detected in any of the offset producers of pilot injectors. The fluid level over the pump and the presence of polymer in the produced fluids were continuously monitored.

The incremental oil production response was observed nine months after the beginning of polymer flooding. This production response was faster than the estimated in the numerical simulation studies. Figure 13 shows the historical behavior of oil production in the influenced production wells (green line).

Additionally, Figure 13 shows the base line (red line) and oil production forecasted (blue line) for the injection polymer solution in both well patterns (PG-34 and PG-37). The oil production patently has been improved showed a huge change in the declination slope despite problems faced during the operation (e.g. very often electrical failures, water restrictions volumes, contractual issues). In order to avoid wrong interpretation it is important to explain that the reduction of the production showed after the start up of the pilot is due to some wells were shut-in down for several months, nothing regarding to the polymer flooding.

Until October 31, 2016, cumulative incremental oil production of 63 KBO has been produced. Additionally, the water cut was reduced about 10 % since the injection of polymer began. The estimated cost per incremental barrel of the pilot is between USD 5-8.

After 1.5 million barrels of polymer solution injected in both patterns, it has been possible to increase the recovery factor in the influenced area. It is important to highlight, that during the pilot execution a positive response of the mobility control associated with the polymer injection and no polymer concentrations have been detected in the effluents of the production wells.

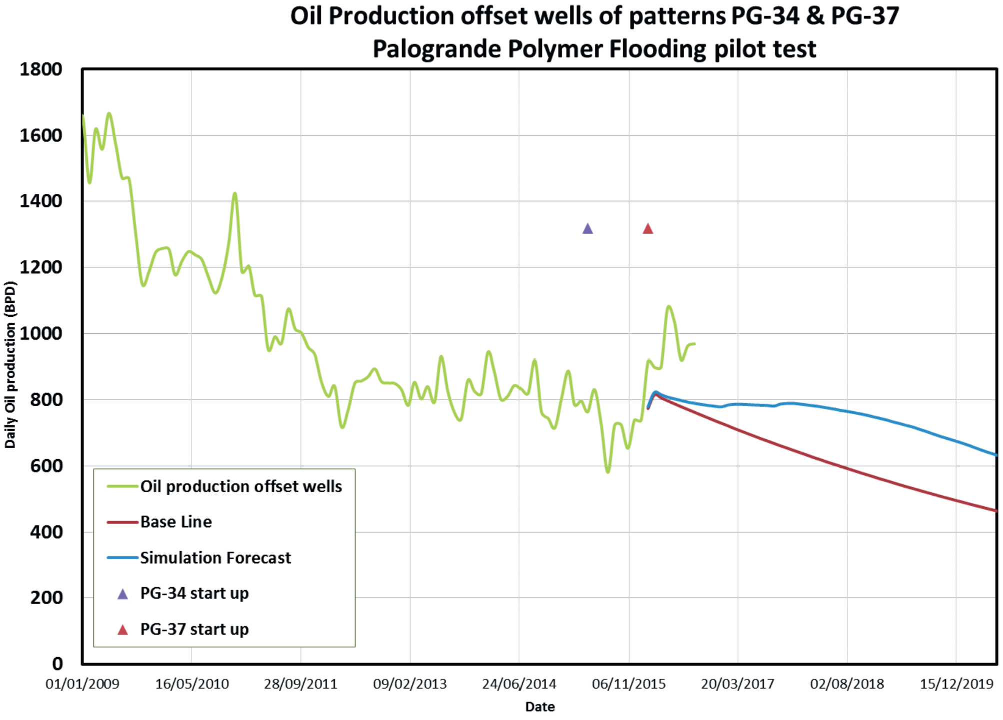

Figure 13. Pilot response of polymer flooding in Palogrande-Cebú Field.

Technical assessment	**Onshore/ offshore**	**Lithology**	**Temp. (°C)**	**Heterogeneity**	**Polymer**	**Formation water TDS (ppm)**	**Polymer injection water quality**
Successful	On.	Sand.	62	YES (DP < 1)	HPAM (5 – 10 MDa)	7 000-10 000	Formation water/ Freshwater
Well spacing (m)	**Polymer injection viscosity (cP)**	**RRF/ RF**	**Oil viscosity (cP)**	***Current*-Cumulative incremental oil (bbls)**	***Final Estimated*-Cumulative incremental oil (bbls)**		
200-300	3.3	1.3/ 5.9	9.4	63 000	962 000		

Table 1. Summary polymer flooding in Palogrande-Cebú Field.

A general description of the polymer flooding pilot in Palogrande-Cebú field is summarized in Table 1. The parameters related are in agreement with review reported by Standnes and Skjevrak (2014).

4. Conclusions

- After 1.5 million barrels of polymer solution injected in wells PG-34 and PG-37 of Palogrande-Cebú Field, an incremental oil production of 63 KBO and a reduction of water cut of up to 10 % have been reported. These results suggest that polymer flood technology represents a technically and economically feasible option to increase the recovery factor in the field.

- The methodology developed by Ecopetrol was successful for the assessment and implementation of the polymer flooding Project in Palogrande-Cebú Field covering the stages of selection of areas, experimental feasibility, reservoir numerical simulation, economic analysis, pilot implementation and monitoring.

- The most common event throughout any pilot project is the response to the continuous changes in operational variables. Manage of electrical failures, injection pressure increases, water quality problems, among others, are key to obtain correct information from the pilot.

- The reported cost per incremental oil barrel of the polymer flood pilot is promising and confirm that the technology could be considered for its expansion in Palogrande.

References

API RP63. Recommended Practices for Evaluation of Polymers Used in API RP63. Recommended Practices for Evaluation of Polymers Used in enhanced oil recovery operations. Washington. 1990.

Barreau, P., Lasseux, D., Bertin, H., Glenat P., Zaitoun A. An experimental and numerical study of polymer action on relative permeability and capillary pressure. *Petrol.Geosci*. 1999. V.5. Pp. 201-206.

Buciak, J., Fondevila, G., Del Pozo, L. Polymer flooding pilot learning curve: 5+ years experience to reduce cost per incremental oil barrel. *SPE Annual Technical Conference and Exhibition*. New Orleans, USA. 2013. SPE-166255.

Castro, R., Maya, G., Mercado, D., Trujillo, M., Soto, C., Pérez, H., Lobo, A., Ordoñez, A., Sandoval, J. E. Enhanced Oil Recovery (EOR) status – Colombia. *SPE Latin American and Caribbean Petroleum Engineering Conference*. Lima, Perú. 2010. SPE-139199.

Castro-García, R.H., Maya-Toro, G.A., Sandoval-Muñoz, J.E., Cohen-Paternina, L.M. Colloidal Dispersion Gels (CDG) to improve volumetric sweet efficiency in waterflooding processes. *CT&F – Ciencia Tecnología y Futuro*. 2013a. 5(3). Pp. 61-78.

Castro, R., Maya, G., Sandoval, J., León, J., Zapata, J., Lobo, A., Villadiego, D., Perdomo, L., Cabrera, F., Izadi, M., Romero, J., Norman, C. & Manrique, E. Colloidal Dispersion Gels (CDG) in Dina Cretáceos Field: From Pilot Design to Field Implementation and Performance. *SPE Enhanced Oil Recovery Conference*. Kuala Lumpur, Malaysia. 2013b. SPE-165273.

Castro, R., Maya, G., Mantilla, J., Diaz, V., Amaya, R., Lobo, A., Ordoñez, A. &Villar, A. Waterflooding in Colombia: Past, present, and future. *SPE Latin American and Caribbean Petroleum Engineering Conference*. Maracaibo, Venezuela. 2014. SPE-169459.

Chang, H.L., Zhang, Z.Q., Wang, Q.M., Xu, Z.S., Guo, Z.D., Sun, H.Q., Cao, X.L., Qiao, Q. Advances in polymer flooding and alkaline/surfactant/polymer processes as developed and applied in the People's Republic of China. *J. Petrol. Technol. 2006.* 58(02). Pp. 84-89.

Delamaide, E., Corlay, P., Wang, D. Daqing oil field: The success of two pilots initiates first extension of polymer flooding in a giant oil field. *SPE/DOE Improved Oil Recovery Symposium*. Tulsa. 1994. SPE-27819.

Du Y., Guan L. Field-scale polymer flooding: Lessons learnt and experiences gained during past 40 Years. *SPE International Petroleum Conference in México*. Puebla, México. 2004. SPE-91787.

Grattoni, C.A., Luckham, P.F., Jing, X. D., Norman L. & Zimmerman, R. W. Polymers as relative permeability modifiers: Adsorption and the dynamic formation of thick polyacrylamide layers. *J. Petrol. Sci. Eng.* 2004. 45(3-4). Pp. 233-245.

Han, P. Determination of reasonable polymer amount in polymer flooding.*Petrol. Geol. Oilfield Dev. Daqing*. 1999. 18(1). Pp. 40-41.

Huh, C., Pope, G.A. Residual oil saturation from polymer floods: Laboratory measurements and theoretical interpretation. *SPE Symposium on Improved Oil Recovery*. Tulsa. 2008. SPE-113417.

León, J.M., Zapata, J.F., Maya, G.A., Castro, R.H., Reyes, J.D., Cabrera, F., Manrique, E. Inyección de geles de dispersión coloidal para el mejoramiento de la eficiencia de barrido volumétrica en procesos de inyección de agua: Del piloto a la expansión. *XVI Congreso Colombiano del Petróleo y Gas*. Bogotá, Colombia. 2015.

Levitt, D.B., Pope, G.A. Selection and screening of polymers for enhanced-oil recovery.*SPE Symposium on Improved Oil Recovery.* Tulsa, USA. 2008. SPE-113845.

Li, Z., Song, X., Wang, Q., Zhang, L., Guo, P., Li, X. Enhanced foam flooding pilot test in Chengdong of Shengli oilfield: Laboratory experiment and field performance. *International Petroleum Technology Conference*. Doha, Qatar. 2009. IPTC-13575.

Manrique, E.J., Muci, V.E., Gurfinkel, M. E. EOR field experiences in carbonate reservoirs in the United States. *SPE Reserv*. *Eval*. *Eng. 2007.* 10(6). Pp. 667-686.

Manrique, E.J., Thomas, C., Ravikiran, R., Izadi, M., Lantz, M., Romero, J., Alvarado, V. EOR: Current status and opportunities. *SPE Improved Oil Recovery Symposium*. Tulsa, USA. 2010. SPE-130113.

Maya-Toro, G.A., Castro-García, R.H., Pachón-Contreras, Z., Zapata-Arango, J.F. Polymer gels for controlling water thief zones in injection wells. *CT&F - Ciencia, Tecnología y Futuro*. 2012. 5(1). Pp. 37-44.

Maya, G., Castro, R., Sandoval, J., Pachón, Z., Jiménez, R., Pinto, K., Diaz, V., Zapata, J., Perdomo, L., Muñoz, S. Successful polymer gels application in a highly channeled peripheral injection well: Tello Field pilot. *SPE Latin American and Caribbean Petroleum Engineering Conference*. Maracaibo, Venezuela. 2014. SPE-169478.

Maya-Toro, G.A., Castro-García, R.H., Jiménez-Díaz, R., Muñoz-Navarro, S.F. Analysis of mixing parameters for polymer gels used for the correction of waterflooding profiles. *CT&F - Ciencia, Tecnología y Futuro*, 2015a. 6(1). Pp. 43-68.

Maya, G., Jimenez, R., Castro, R., Mantilla, J., Vargas, J., Cardenas, F., Fernandez, F., Quintero, H., Zaitoun, A., Manrique, E., Romero, J., Putnam, J. Design and implementation of the first polymer flooding project in Colombia: Yariguí-Cantagallo Field. *SPE Latin American and Caribbean Petroleum Engineering Conference*. Quito, Ecuador. 2015b. SPE-177245.

Putz, A. G., Lecourtier, J. M., Bruckert, L. Interpretation of high recovery obtained in a new polymer flood in the Chateaurenard field. *SPE Annual Technical Conference and Exhibition.* Houston. 1988. SPE-18093.

Putz, A. G., Rivenq, R. C. Commercial polymer flooding in the Courtenay field. *J. Pet. Sci. Eng*. 1992. 7(1-2). Pp. 15-23.

Mogollón, J., Lokhandwala, T. Rejuvenating viscous oil reservoirs by polymer flooding: Lessons learned in the Field. *SPE Enhanced Oil Recovery Conference*. Kuala Lumpur, Malaysia. 2013. SPE-165275.

Mungan, N., Smith, F.W., Thompson, J.L. Some aspects of polymer floods. *J. Petrol. Technol.* 1966. 18(09). Pp. 1143-1150.

Seright, R.S., Seheult, M., Talashek, T. Injectivity characteristics of EOR polymers.*SPE Annua Technical Conference and Exhibitionn*. Denver, USA. 2008. SPE-115142.

Sheng, J. *Modern chemical enhanced oil recovery – Theory and practice*. Oxford: Elsevier. 2011.

Sorbie, K. *Polymer-improved oil recovery*. Florida: CRC Press. 1991.

Standnes, D. C., Skjevrak, I. Literature review of implemented polymer field projects. *J. Petrol. Sci. Eng*. 2014. 122. Pp. 761-775.

Wang, D.M., Dong, H.Z, Lv, C.S., Fu, X.F., Nie, J. Review of practical experience of polymer flooding at Daqing. *SPE Reserv. Eval. Eng.* 2009. 12(03). Pp. 470-476.

Weiss, W., Baldwin R. Planning and implementing a large-scale polymer flood. *J. Petrol. Technol*. 1985. 37(04). Pp. 720-730.

Yuan, C. Simulations of subsurface multiphase flow including polymer flooding in oil reservoirs and infiltration in vadose zone. *Thesis of Master Science*. University of Texas at Austin. Austin, USA. 2009.

Zhang, Y., Wei, M., Bai, B., Yang, H., Kang, W. Survey and data analysis of the pilot and field polymer flooding projects in China. *SPE improved Oil Recovery Conference*. Tulsa, USA. 2016. SPE-179616.

Zheng, C.G., Gall, B.L., Gao, H.W., Miller A.E., Bryant, R.S. Effects of polymer adsorption and flow behavior on two-phase flow in porous media. *SPE Reserv.Eval. Eng.* 2000. 3(03). Pp. 216-223.

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