Hydra-Cell® Diaphragm Pump Technology for Minimizing Shear Effects in EOR Polymer Solutions

Phase II Report

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1 Introduction

Polymer flooding continues to be the dominant form of chemical-enhanced oil recovery. It is one of the few methods that has concrete proof of concept and economic advantage. Although these projects account for the most oil produced via chemical injection, there are many operational and design considerations that drastically affect field performance.

Besides emulsions and water quality issues, polymer degradation has the largest effect on the economics of these projects. Polymer quantity, viscosity, and injectivity drastically affect the CAPEX / OPEX expenses, cumulative production, and reserves in these projects.

This report is intended to organize past experiences, simulation results, literature review, and the technical understanding of the effects that pumps have on polymer solutions to characterize the extent of the benefits that low-shearing Hydra-Cell hydraulically actuated diaphragm pumps (manufactured by Wanner Engineering, Inc.) can have on polymer flooding projects through lower shear degradation.

Hydra-Cell model T100K, manufactured by Wanner Engineering, Inc., Minneapolis, Minnesota, USA.

2 Industry Review

Much of the science and literature pertaining to polymer degradation is on porous media and chemical degradation, with some limited focus on surface facilities (pumps, chokes, piping, etc.). Pumps are largely ignored in these projects, even though the pump is one of the first pieces of equipment the polymer slug comes into contact with and is one of the first points of significant shear degradation of the polymer solution.

Mechanical degradation can result in significant viscosity loss due to the irreversible scission of polymer macromolecules. It can occur in the injection facilities (turbulent flow), before the polymer solution reaches the formation, or in the near-wellbore area (laminar flow) [34]. Scissoring occurs when a polymer solution is exposed to high shear conditions, such as during the mixing of polymer solutions or the conveyance of a polymer solution in pumps and chokes [23].

What has typically been done to mitigate the shear degradation in surface pumps has been to use progressive cavity and triplex plunger pumps. Progressive cavities have seen some use as deliverers of “mother solution” (extremely viscous, high-concentration polymer solution) but have lacked use for pumping downhole due to the operational costs, complexity, and rigorous maintenance that requires long periods of downtime. Triplex plunger pumps are the current choice for operators of polymer floods. These pumps see shear degradation values up to 15% of the solution viscosity [13]. Attempted remedies for these issues include over-sizing the plunger pump and slowing the RPM, creating a non-optimized and more expensive solution while still causing turbulent flow and degradation of the polymer solution.

Laboratory experiments at the University of Wyoming showed, on average, the Hydra-Cell T100K demonstrated a 1-5% degradation of polymer viscosity. Results also demonstrated no consistent trend between the percent decrease in viscosity and either the discharge pressure or the pump flow rate. The experimental system and piping did have a non-negligible impact on polymer solution viscosity reduction, suggesting that polymer degradation through the T100K is most likely even less than the measured 1-5% viscosity reduction. Overall, Wanner Engineering’s Hydra-Cell T100K has demonstrated a marked improvement and decrease in polymer solution viscosity degradation over what is generally seen in oilfield projects (≈15%) [14].

2.1 Economics of Polymer Flooding

Polymer flooding costs range from USD $3-$12 per incremental barrel produced. The high range covers special polymers for high temperature/salinity conditions and can be improved when pilots are expanded to a commercial scale. However, polymer flooding can be very sensitive to project economics. Typically, these projects are first driven by capital expenditures, with operational expenses getting lumped into the “per incremental barrel” cost.

With chemical EOR costs typically being reported at an inclusive cost per incremental barrel of oil basis, long-term consequences of CAPEX decisions are unknowingly funneled into rising OPEX costs. For example, if a high shear triplex pump were purchased due to lower upfront costs, CAPEX would show up favorably on the balance sheet; however, over time, the OPEX costs would rise as more polymer is purchased to overcome the additional degradation and reduced mobility control of the polymer solution.

With Hydra-Cell pumps’ lower degradation [14], significant savings can be realized through lower polymer utilization and higher cumulative production. Hydra-Cell pumps also do not require seals or packing and will often pay for themselves in just maintenance costs alone versus a triplex plunger pump (see Table 1).

Table 1: Hydra-Cell costs compared to typical plunger pumps.

Life Cycle Cost Analysis of Polymer Injection Pumps for EOR
Total Costs: Acquisition and 3 Years of Operation

	Packed Plunger Pump #1	Packed Plunger Pump #2	Hydra-Cell T Series
Corrective Maintenance Cost (Break-down events. Includes labor @$100 per hour, spare parts.)	$44,940	$33,000	$6,441
Preventive Maintenance Cost (Includes labor @$100 per hour, spare parts.)	$24,816	$17,196	$12,582
Energy Cost (8,760 working hours per year @$0.15 per KWh)	$35,478	$35,478	$35,478
Acquisition Cost (Pump and driver skid)	$84,950	$65,764	$76,302
Total Cost per Pump (3 years)	$190,184	$151,438	$130,803
Hydra-Cell Saving by Pump	**$59,381**	**$20,635**	

3 Reservoir Engineering

Typical polymer flooding viscosity design is directed by mobility ratio, with resistance factor (i.e., injectivity and project economics) being the final design criteria for target viscosity and molecular weight of polymer to be used. This ensures a reasonable flow rate through the reservoir and injection pressures below fracture pressures. Pilot projects typically take up to three years to design and another two to four years to see a full field-scale development (Fig. 1).

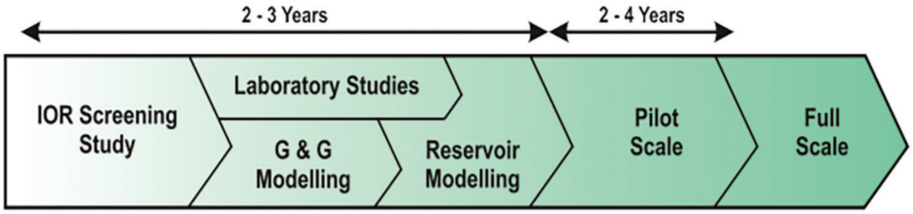

Figure 1: Typical timeline from screening to full-scale deployment (modified) [30].

It is imperative that the target viscosity is reached for the flood to be successful. Simulation and reservoir engineering often do not include shearing in surface facility equipment such as pumps. If the facilities shear/degrade polymer enough, it can drastically alter the profitability of the operation. As can be seen from Table 2, concentration and pounds of polymer per volume reservoir are significant economic drivers in these projects. The less shear degradation in a system, the lower the amount of bulk polymer needed.

Table 2: Polymer flooding summary in the United States [28].

	Sandstone Projects (273)	Carbonate Projects (55)
Polymer conc. (ppm)	50-3,700	50-1,000
Polymer used $\left(\frac{\text{lb.}}{\text{acre–ft.}}\right)$	19-150	12-56
Oil recovered $\left(\frac{\text{STB}}{\text{lb. polymer injected}}\right)$	0-3.74	0-2.82
Recovery (% OOIP)	0-23	0-13

3.1 Simulation & Sensitivity Analysis

Sensitivity analyses were run in CMG's CMOST AI to see the effects that polymer molecular weight, assigned polymer viscosity, and polymer mixing function (polymer viscosity vs. concentration) had on the cumulative oil production on a selected simulation study. The study was run on CMG's template "stflu020.dat," a surfactant polymer flood whose data and grid are based on well-published SPE papers [35] [11] [20]. The only modification made to the model was to keep injection rates constant. If viscosity is altered without constant injection parameters, lower viscosity simulations can artificially increase production from an increase of allowable injectant to increase pore-flooded reservoir volumes.

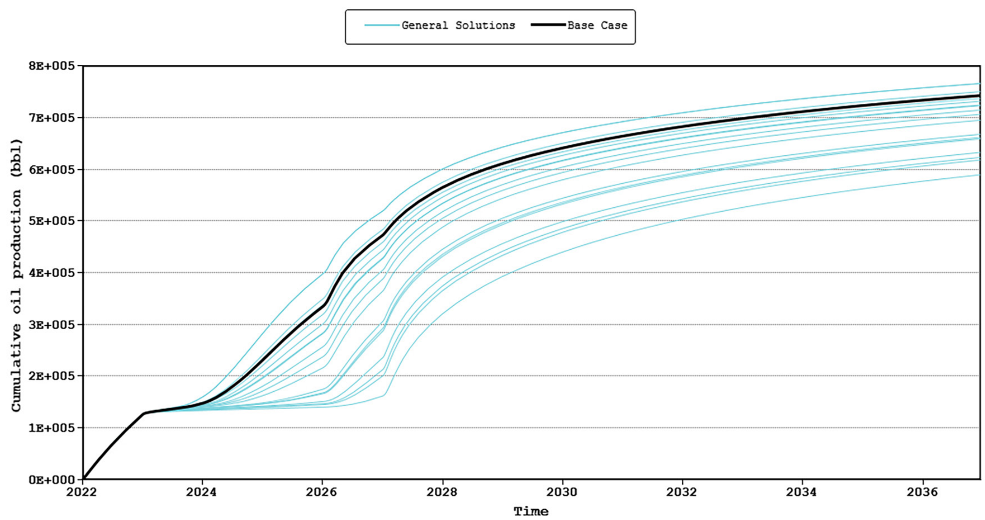

Figure 2: Sensitivity analysis of molecular weight, viscosity, and polymer mixing function on cumulative oil production.

Our results showed a decrease of up to 30% in cumulative oil production through varying the three parameters (Fig. 2), which confirmed the results in Sorbie's monograph on degrading polymer solutions and their negative effect on cumulative oil production (Fig. 3). This significant decrease can ultimately be the decider if a project is profitable or not.

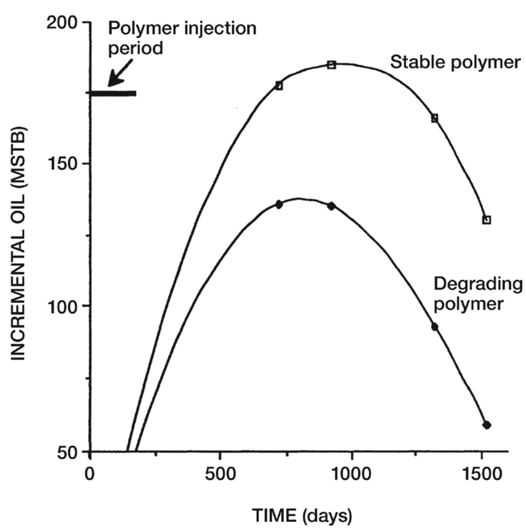

Figure 3: Incremental oil in 3-D field calculations [41].

4 Conclusions

Often overlooked, surface facility pumps are often culprits of large amounts of shear degradation in polymer slugs, which can lead to drastic decreases of up to 30% in cumulative oil production [41]. With low-shear pump technology such as the Wanner Hydra-Cell pumps, operators can extend the financial recovery of wells on polymer injection and see an increased rate of return.

Table 3: Key economic parameters for different EOR methods (from experience and confidential reports).

Method	Key Parameter	Typical Parameter Value	Key Parameter Cost (USD $)
Gas (CO2)	Utilization factor	2.4 – 11 mcf CO2/BBL (miscible)	$1 - $2/MMSCF natural
		5 – 12 mcf CO2/BBL (immiscible)	$20 - $30/MMSCF anthropogenic
		<20 mcf CO2/BBL (economic limit)	
Thermal	Steam oil ratio (SOR)	2 – 8 volume steam per unit oil volume	$3 - $8 per steam BBL
A/SP	Price per incremental BBL	All-inclusive cost per BBL	$10 - $15/BBL
Polymer	Price per incremental BBL	All-inclusive cost per BBL	$3 - $12/BBL

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