Suffield Polymer Core Flood Study - A Key Component of the Pilot Project*

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Abstract

The Suffield polymer core flood study is a key part of the polymer flood pilot with objectives to screen a suitable polymer and concentration for field application and evaluate the potential of polymer flood under reservoir conditions. The Suffield polymer pilot was based on the results of polymer core flood study and provided important data (recovery factor, time to see production response and oil rate etc.) to evaluate the pilot. The study includes core plug selection, core characterization, screening suitable chemical formulations (polymer, surfactant (S), alkaline/surfactant/polymer (ASP)) and core flooding experiments with polymer (S or ASP). The polymer pilot has been in place for over two years with successful results showing oil cut increasing to 20% from 4% and oil production at 600 bbl/d up from 400 bbl/d. It has demonstrated that the core flood study is a reliable guide for field application.

Introduction

The Suffield Caen reservoir geology is complex with thin net pay and edge water producing heavy oil of 17°API. The field had been under water flooding over 15 years with poor sweep efficiency due to the high water/oil mobility ratio. Recovery factor was 20% and water cut average was 96%. There is an irregular injection pattern due to military base surface restrictions. This added to the complexity of a reservoir simulation model that was established to represent the reservoir geometry and edge water with good history match. Core flood evaluations including polymer, SP, and ASP were conducted in 2009 to evaluate the potential of chemical flood applications using available produced water from the reservoir as well as choosing a suitable polymer and polymer concentration for the polymer flood. Based on the core flood results and economic evaluations a specific polymer formulation was selected as the option for a pilot project and the polymer injection commenced in December 2010. Current plans are to extend the polymer flood based on early production response and overall success of the pilot.

Reservoir Geology

Glauconitic Channel Facies

The Glauconitic channel sands of the Caen Pool are several kilometers long and 1 to 3 km in width and are comprised of quartzose sand up to 9.8 m thick (Figure 1). These sands were deposited in a northerly flowing river system and are fine to medium grained. Producing pools generally form elongate pods within the main channel trend with up to 9.8 m of oil pay with no bottom water (Figure 1 and Figure 2). Lithologically, these channels are quartzose with porosities of 15 to 29 percent and permeable intervals of more than 2000 millidarcies. On well logs, the gamma–ray count of clean sandstone is generally less than 30 API units. These channel sands did not have any bottom water initially, which made them ideal candidates for polymer injection. Water has been injected since 1996 to maintain reservoir pressure and improve well performance. The north half of the pool has been subject to a polymer flood since late 2010 and due to the success of the project plans are proceeding to expand the flood further south (Figure 2).

The Glauconitic is shown on wire line logs (Figure 3) with the reservoir parameters summarized in Table 1.

Reservoir Geometrics

The reservoir simulation model represents complex reservoir geometrics, edge water and OIP distribution (Figure 4).

Core Lab Evaluation

Core Plug Selection

The core plugs were selected from the Glauconitic formation from two wells (102/16-15-016-09W4/00 and 100/11-14-016-09W4/00) in the Caen field and are representative of the Caen reservoir. The plugs are 3.8 cm in diameter and 6 cm in length (Figure 5). Fifteen core plugs were selected for three possible core floods. The core floods were conducted on stacked plugs of 3.8 cm in diameter and 30 cm long.

Core Characterization

The selected core plugs were placed into a lead sleeve and mounted into a core holder. The core was then flooded sequentially with solvents to remove residual oil. The core was dried later to remove any solvents and subsequently evacuated. After air permeability Ka and porosity Φ are measured, the core was saturated with produced brine to establish the pore volume and brine permeability Kw.

Two coreflood tests were conducted to evaluate the polymer flood potential after waterflood. The coreflood experiments were carried out using stacked reservoir core plugs in lead sleeve under net over burden pressure of 6.9MPa, at a constant reservoir temperature of 21°C with system pressure maintained at 10MPa. After the core was cleaned and imbibed with reservoir brine, live oil was injected to displace mobile water until a constant pressure drop across the core was obtained and water production stopped. The oil permeability at connate water saturation was determined after the core was aged for over 14 days. The core properties are summarized in Table 2.

Screen polymer and concentration

Four kinds of polymers were tested in synthetic Caen injection brine for filterability of stock solutions and viscosity as a function of polymer concentration. Figure 6 shows the bulk shear viscosities (at shear rate of 7s-1) for the four polymers at three concentrations (750ppm, 1500ppm and 2000ppm). The 1500ppm Flopaam 3630 was selected to be injected in coreflood tests.

Core Floods

Both core floods started with water flood followed by polymer flood at an injection rate corresponding to a linear frontal advance rate of 0.32m/day. In Core flood 1, the water flood recovered 13% OOIP after 0.78 PV of brine injection. The injection of the following polymer solution using 1500ppm Flopaam 3630 led to an incremental oil recovery of 32% OOIP after 0.5PV of polymer injection.

In Core flood 2, more heterogeneous core plugs were used to reflect the real reservoir situation. After 1.5 PV of water flood, the cumulative oil recovery was about 20% OOIP. The injection of the following polymer solution using 1500ppm Flopaam 3630 led to significant increase in both mid-core and full-core pressure drops. With oil banked ahead of the polymer front, water cut dropped to as low as 21%. The incremental oil recovery after 0.5 PV of polymer injection was 29% OOIP. The pressure profiles and oil recovery during the water flood and polymer flood in Core flood 2 are shown in Figure 7. The core flood results are listed in Table 3.

Following polymer flood, selected SP and ASP formulations were injected to evaluate the potential of recovering incremental oil over polymer flood. The SP formulation did not generate any incremental oil recovery because of the high surfactant adsorption. The optimized ASP formulation achieved an incremental recovery 7% OOIP after polymer flood. The above lab evaluations indicated that polymer flood showed promise in achieving the maximum incremental oil recovery with the best economic results. Therefore, polymer flood was selected for pilot in the Caen reservoir.

Evaluation of Polymer Flood Pilot

A reasonable economic model was established to evaluate the polymer flood pilot based on core flooding results. They are:

- 0.6 PV of polymer injection would be injected for the pilot based on the maximum recovery oil achieved by 0.5 PV of polymer injection
- The time to see oil production response was when the volume of polymer injection reached 0.2PV
- The oil rate increase and peak production were estimated using 30%of the core flood results
- Total recovered oil from polymer flood is 10% OOIP, 30% of the core flooding results

By running the model with Value Navigator, the pilot appeared to be economic and promising. Figure 8 shows the pilot production forecast based on core flood results and pilot actual oil production.

Conclusions

The core flood study demonstrated that the polymer flood could improve oil recovery within the Caen reservoir by generating a more favorable mobility ratio and improving sweep efficiency; it is a key step and provides valuable information regarding field applications of polymer solution to enhance oil recovery. There are a large number of conventional heavy oil reservoirs in the Western Canada Basin with recovery factors of only 10% to date and there is the potential to recover significant additional oil by polymer flood.

Acknowledgements

The core flood experiments by Alberta Innovates Technology Futures (Alberta Research Council) are gratefully acknowledged.

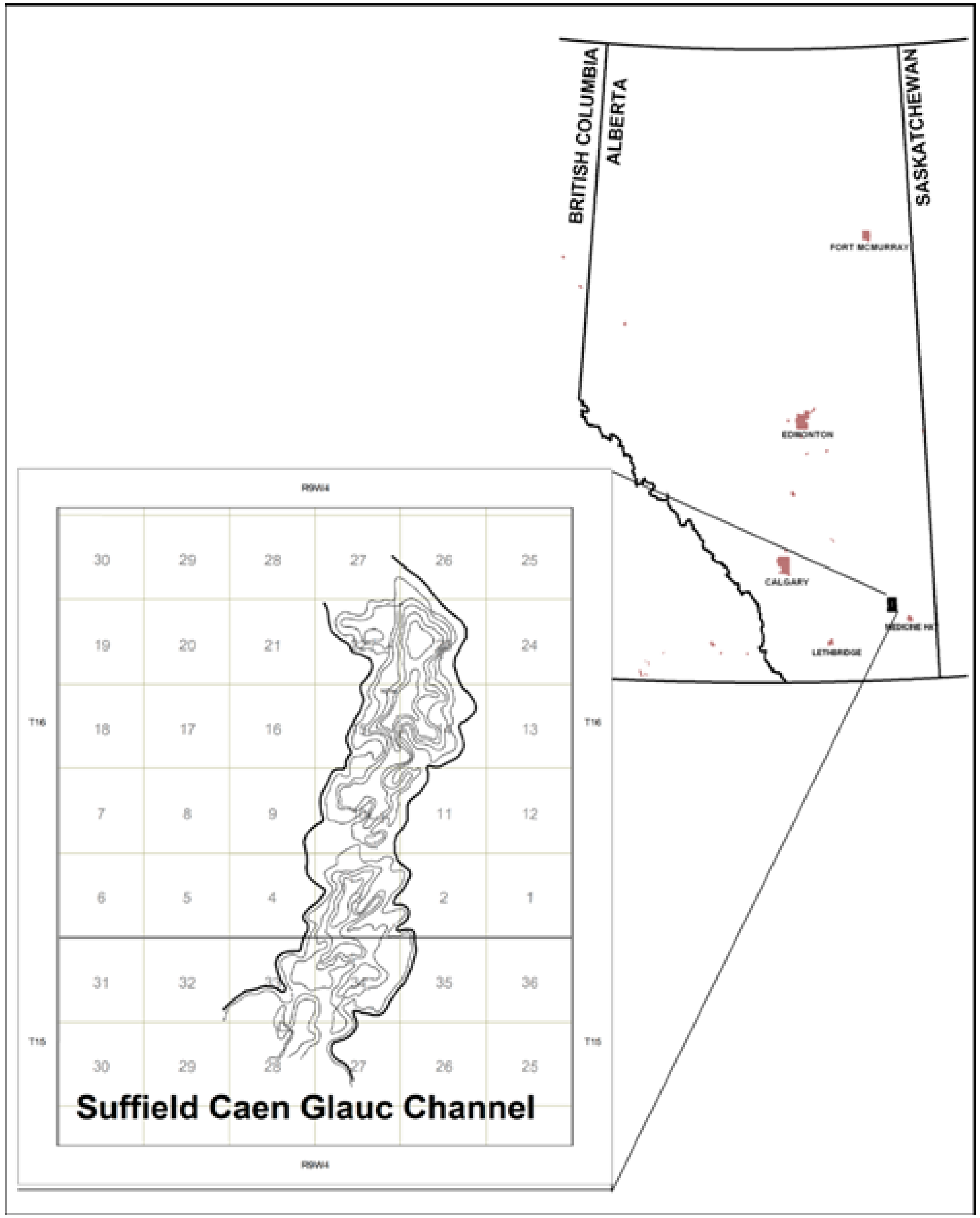

Figure 1. Index map showing location of Caen Glauconitic channel.

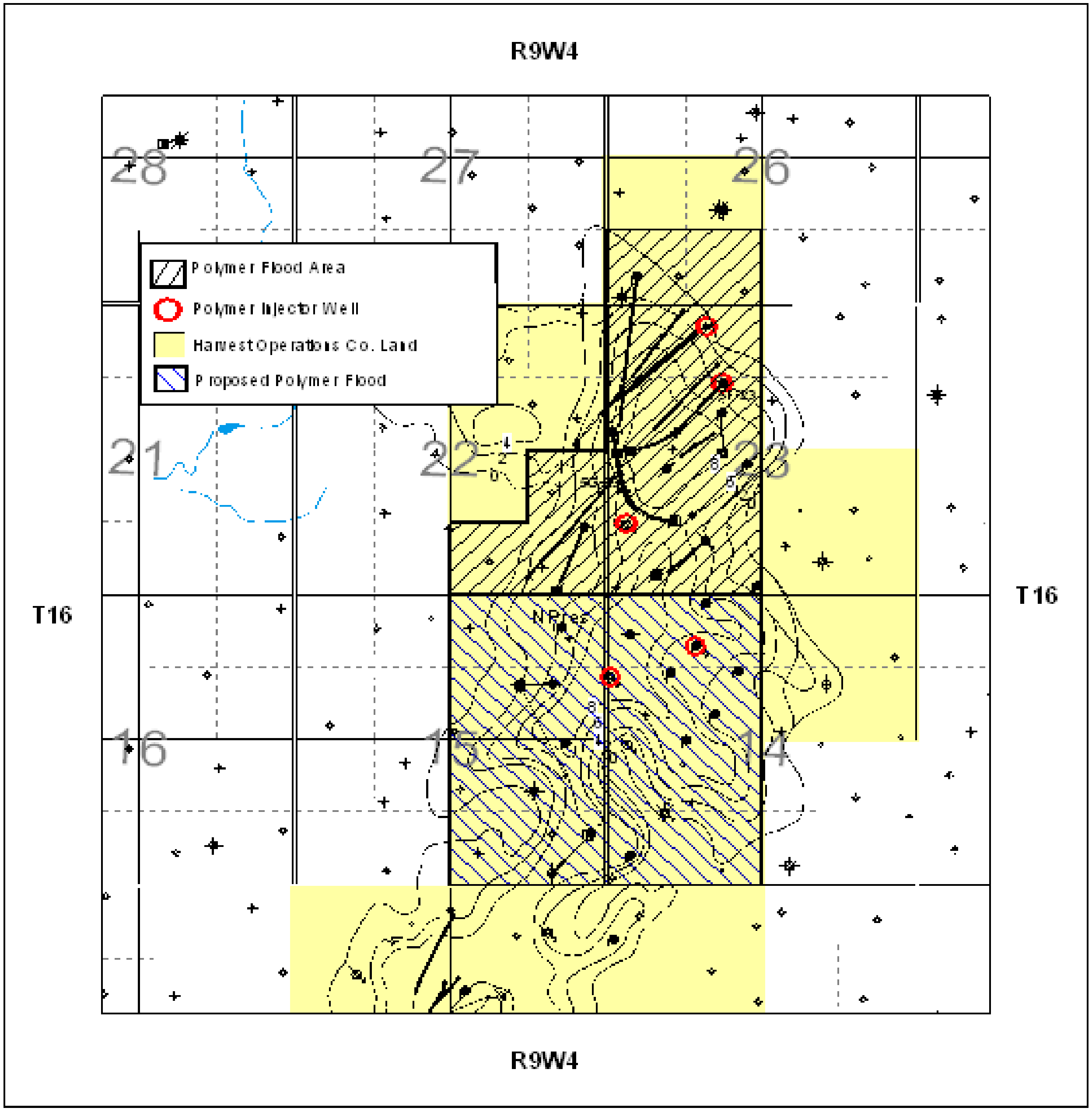

Figure 2. Caen polymer pilot area.

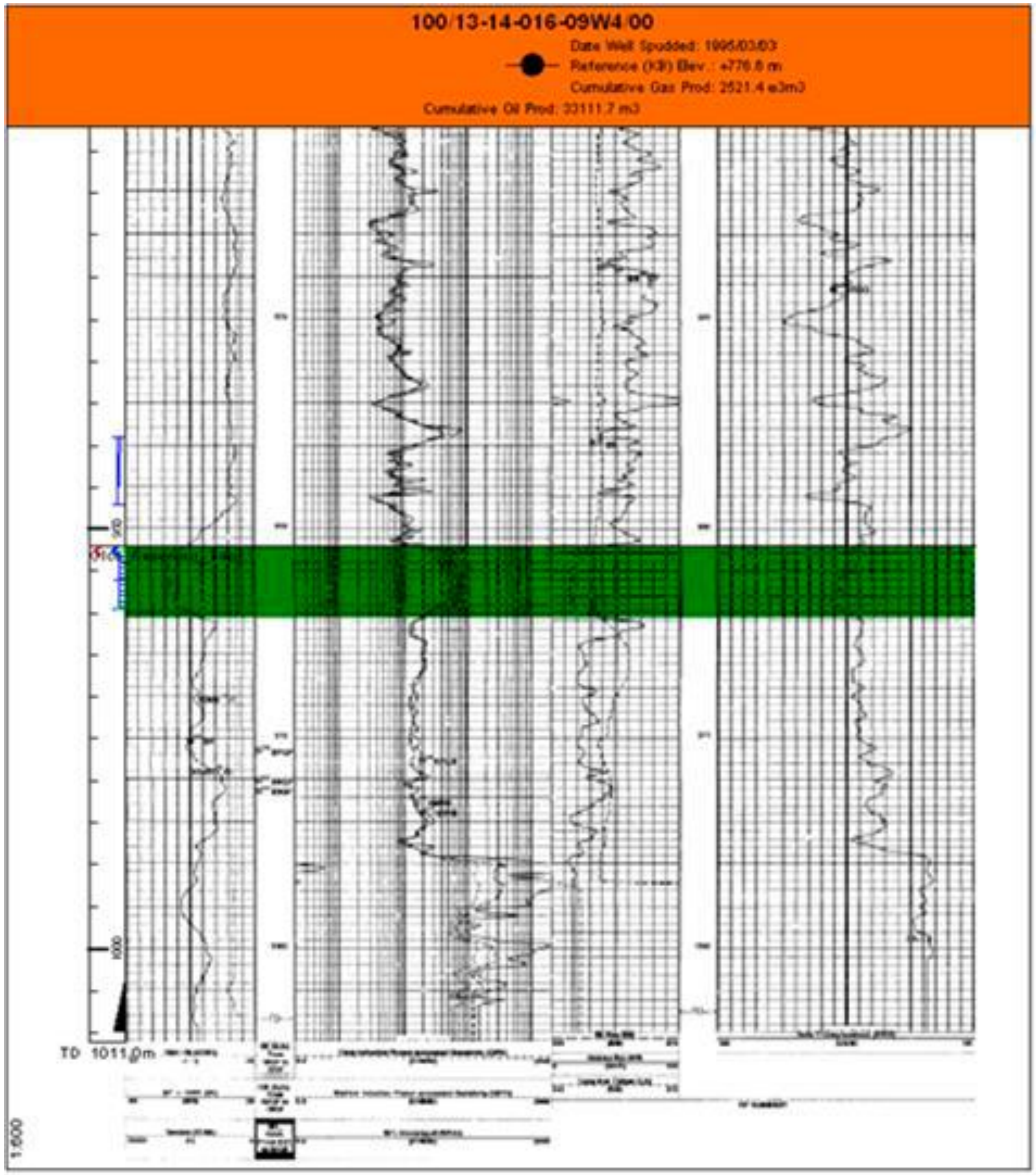

Figure 3. Caen reservoir type log.

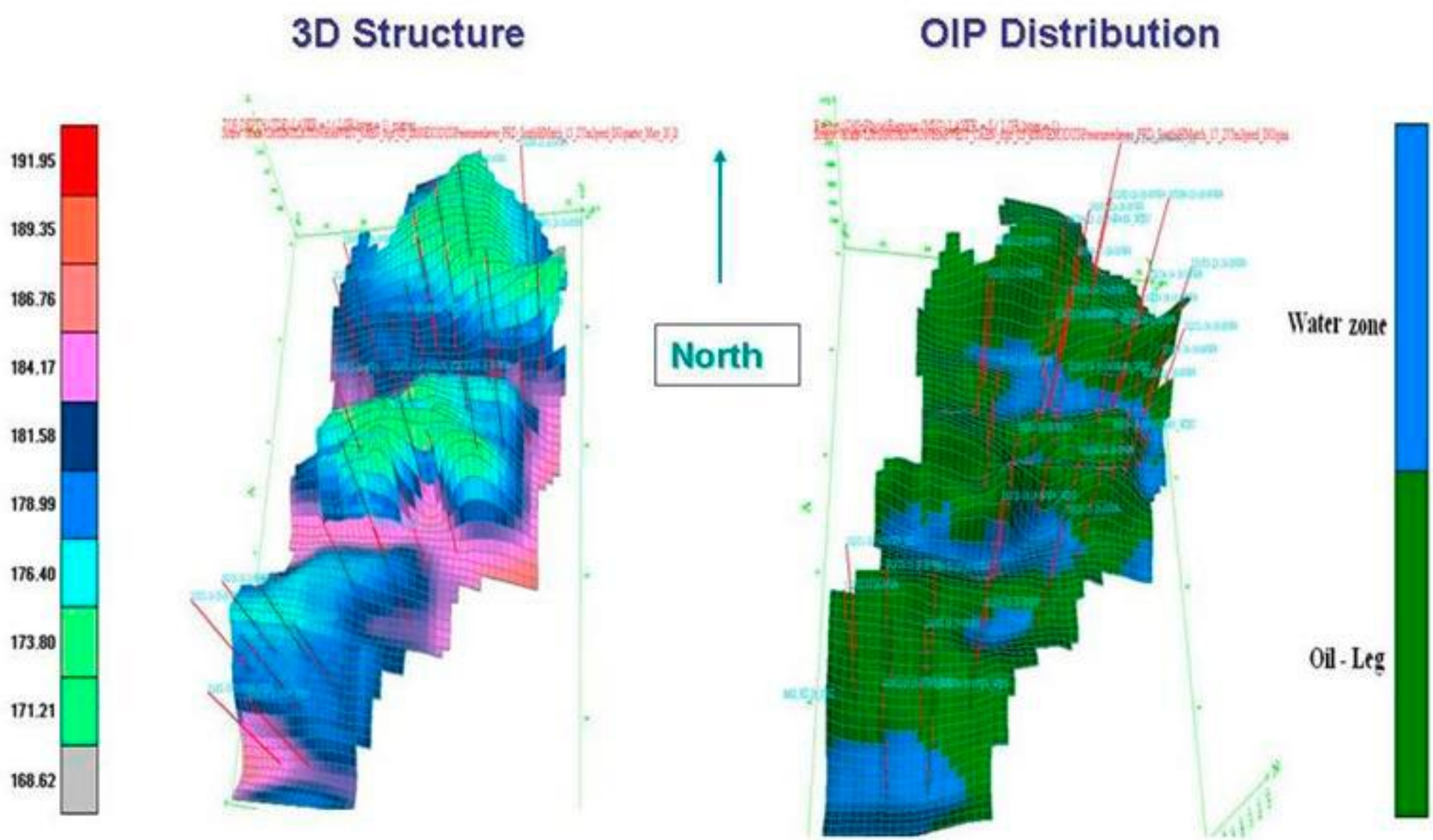

Figure 4. Reservoir geometrics from reservoir simulation.

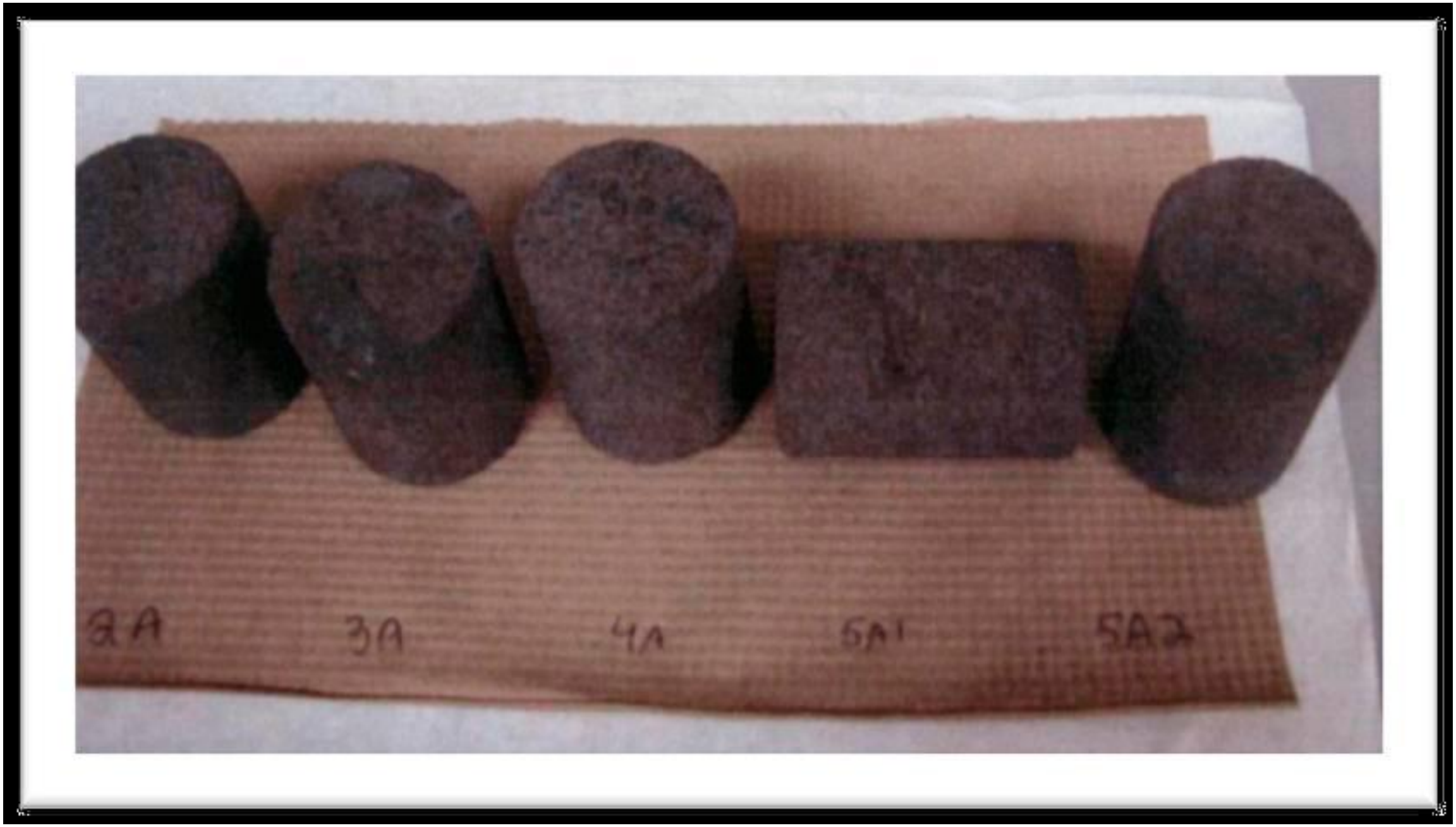

Figure 5. Selected core plugs used in coreflood 1.

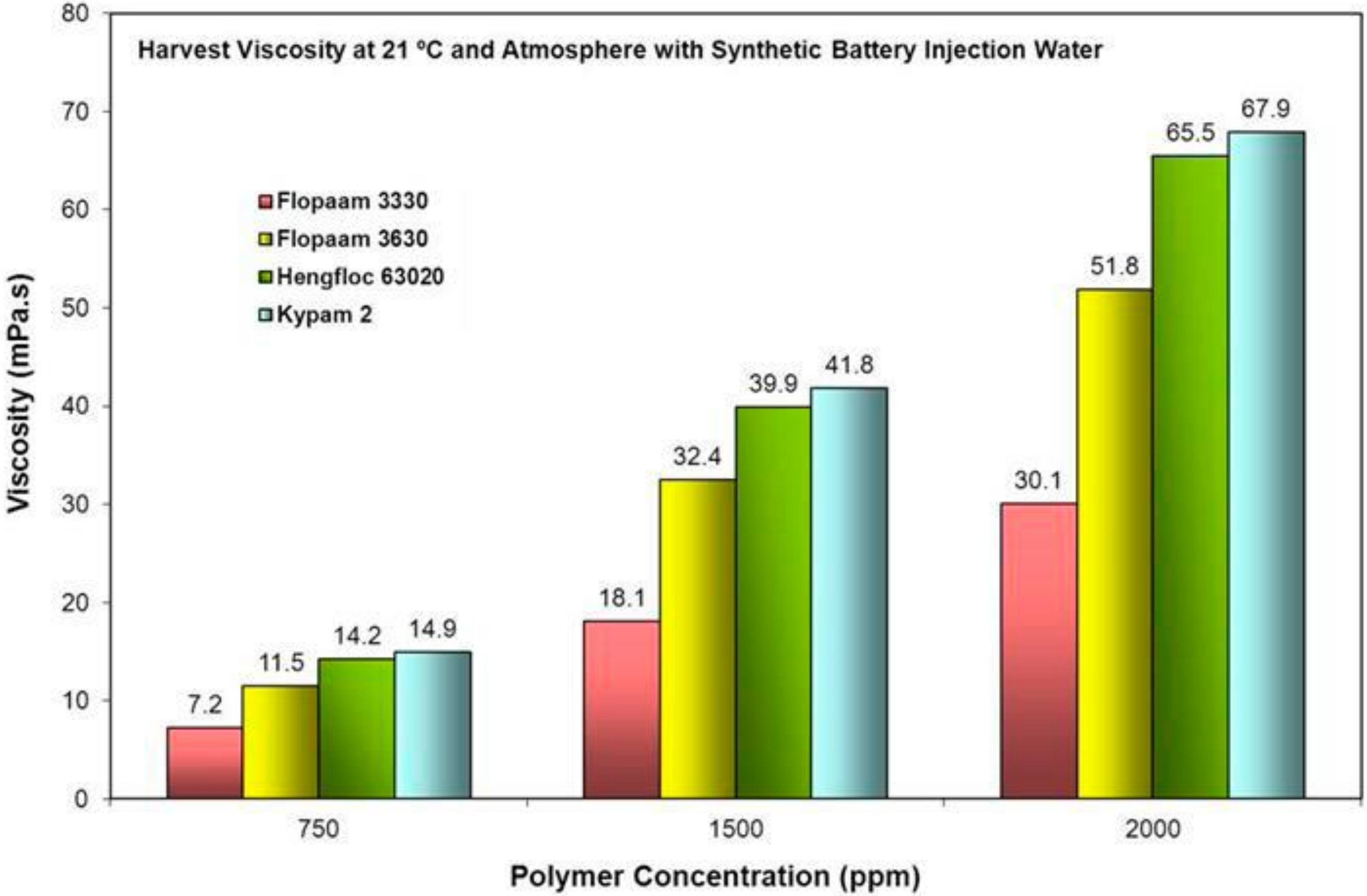

Figure 6. Polymer viscosity versus concentration at reservoir condition.

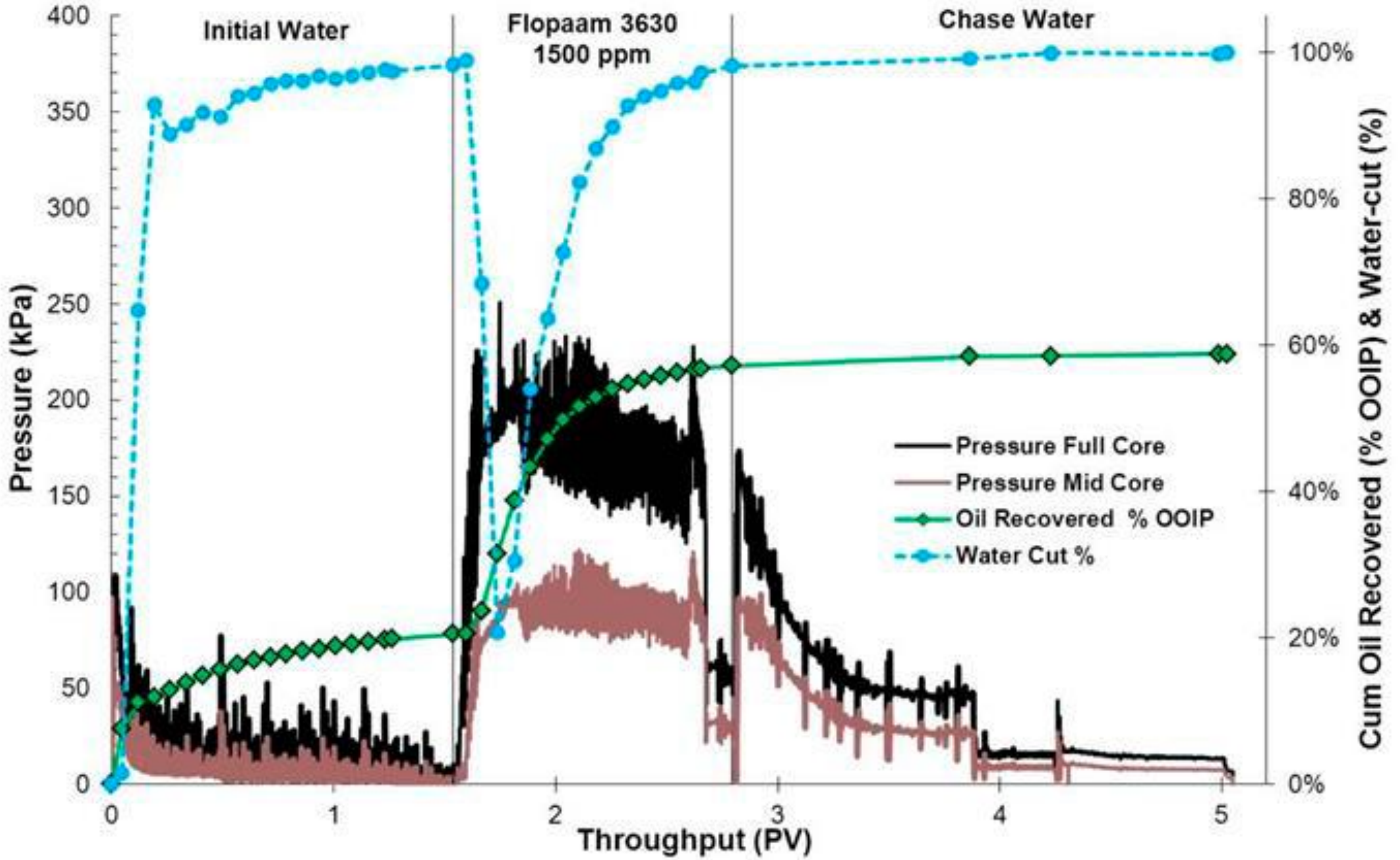

Figure 7. Oil recovery and pressure responses during water and polymer flood in coreflood 2.

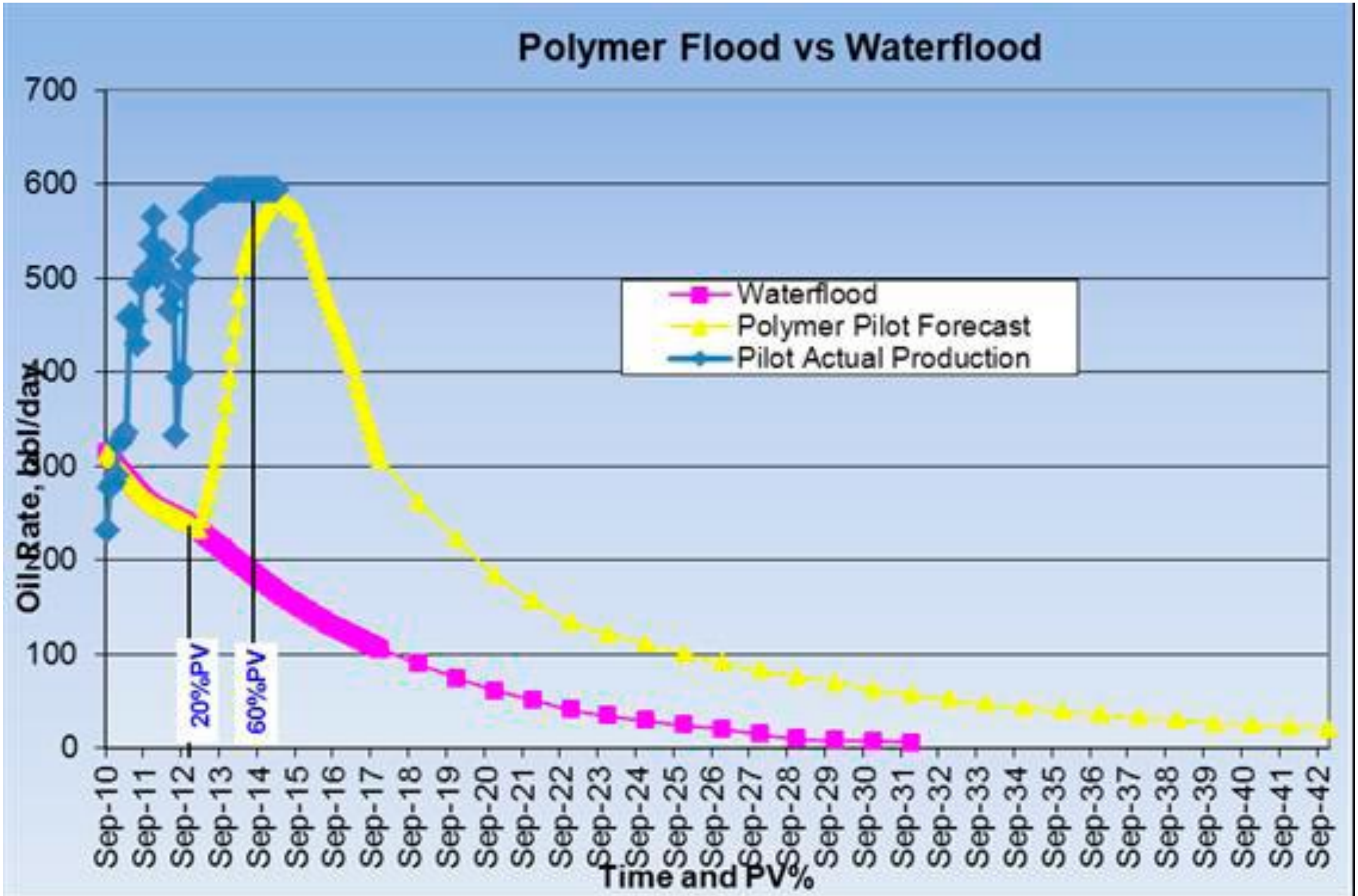

Figure 8. Pilot forecast versus actual oil production.

Initial reservoir pressure (KPa)	10436
Porosity (%)	26.5
Permeability (mD)	500 - 2000
Initial Water Saturation (%)	32.5
Bubble Point Pressure (KPa)	7791.1
Original Oil Water Contact (m)	-186.6
Dead Oil Viscosity (cp)	378.6— 591.7
Live Oil Viscosity (cp)	69.5 — 200.0
GOR (m^3/m^3)	26.52
Temperature (℃)	21

Table 1. Reservoir parameters.

Core Properties	Coreflood 1	Coreflood 2
Core Type	Reservoir Core	Reservoir Core
Weight (g)	552.83	630.93
Length (cm)	25.32	29.73
Bulk volume (cm^3)	287.37	334.96
Porosity (%)	27.8	27.8
Pore volume (PV) (ml)	79.88	93.25
Core temperature (℃)	21	21
Net overburden pressure (kPa)	6895	6895
Air permeability (mD)	2552	1851
Brine permeability (mD)	2133 @ 21°C and 1450psi	676
Oil flow rate (cm^3/h)	4.2	4.8
Waterflood rate (cm^3/h)	4.2	4.2

Table 2. Core properties.

Parameter	Coreflood 1	Coreflood 2
K (md)	2133	676
k_o at S_{wi} (md)	1470	724
S_{wi} (%)	0.24	0.27
S_{oi} (%)	0.76	0.73
S_w (after initial water flood) (%)	0.34 (0.78PV)	0.42 (1.54PV)
S_w (after polymer slug) (%)	0.75 (4PV)	0.69 (1.26PV)
S_o (after polymer slug) (%)	0.25 (4PV)	0.31 (1.26PV)
S_{or} (final) (%)	0.25	0.30
Water flood oil recovery (%OOIP)	12.9 (0.78PV)	20.53 (1.54PV)
Polymer flood oil recovery at 0.5PV (%OOIP)	32.0	29.3
Polymer flood oil recovery (%OOIP)	53.9 (4PV)	36.62 (1.26PV)
Final oil recovery (%OOIP)	66.8	57.2

Table 3. Core flood results.