STUDY ON NATURE/SYNTHESIZED POLYMERS COMBINED WITH NANOPARTICLES ON SECONDARY RECOVERY TO MAXIMIZE OIL RECOVERY

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Introduction

- Enhanced Oil Recovery (EOR) techniques have been employed to increase the recovery factor of oil reservoirs.
- Polymer flooding is a well-established technique for enhancing oil recovery from reservoirs.
- The process involves injecting water-soluble polymers into the reservoir to increase the viscosity of the injected fluid, reduce the mobility ratio, and improve sweep efficiency.

Introduction

- Several polymers have been used for this purpose, including Xanthan Gum, and Partially Hydrolyzed Polyacrylamide (HPAM).
- Determination of the optimum polymer concentration is one of the crucial steps in the planning phase of a certain polymer flooding project.
- Most of polymers used in EOR projects loses their abilities of viscosifying and degrade at harsh reservoir conditions (HSHT).

Problem Statement

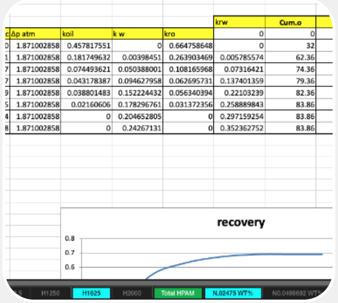
- High salinities can accelerate the degradation of polymers. Salts present in the reservoir brine can lead to the breaking of polymer chains, reducing their viscosity and effectiveness as flow modifiers. This degradation can result in reduced oil recovery efficiency.

Study Objectives

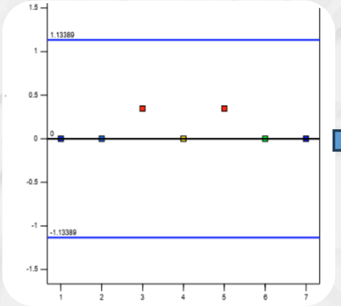
- This study aims to give a comparison between Xanthan Gum (natural) and HPAM (synthesized) under various conditions and their effect on oil recovery.
- Observe the effect of silicon dioxide SiO_2 (nanoparticles) on the oil recovery, Use Silicon dioxide combined with each of the polymers and observe their effects on the oil recovery.

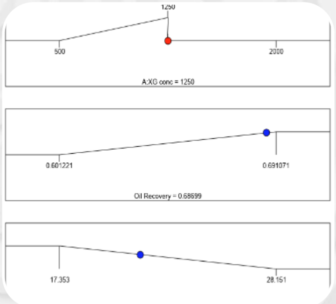
Design Expert Software

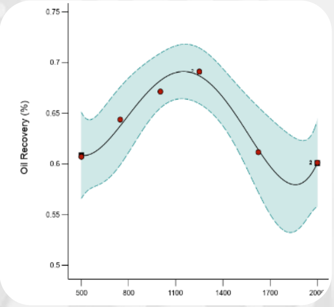
Factor 1 A:XG conc ppm	Response 1 Oil Recovery %	Res
500		
1625		
1250		
1002.5		
1250		
747.5		
2000		



Factor 1 A:XG conc ppm	Response 1 Oil Recovery %	Res
500	0.607143	
1625	0.611607	
1250	0.691071	
1002.5	0.671429	
1250	0.691071	
747.5	0.64375	
2000	0.601221	







Creating design: Using statistical analysis, it generates a design matrix.

Collecting data: According to the generated design matrix, the actual experiment is performed and then the collecting of the response data occurs.

Data Entry: The data collected is recorded in the design matrix.

Analysis and Modelling: It builds a model to represent the relationship between the factors entered and the responses using ANN by analyzing the data.

Optimizing Model: The software offers tools to optimize the system being studied to identify the optimal factor settings that maximize the desired response which in our case the oil recovery.

Visualization and Interpretation: It provides visualizations and graphical tools, such as 3D plots, interaction plots, and contour plots.

Methodology

1. Chemicals used:

Table 1. Oil properties (lab measured)

Oil Properties	Acid number	0.8 mg KOH/gm oil
	Viscosity	2.464 cp at 30ºC and 1 atm
	Density	0.814 gm/cc at 30ºC and 1 atm
	API	41.81º

Table 2. Polymers and nanoparticles concentrations

	Type	**Concentrations**					
Polymers	HPAM (ppm)	500	747.5	1002.5	1250	1625	2000
	Xanthan Gum (ppm)	500	747.5	1002.5	1250	1625	2000
Nanoparticles	Silicon Dioxide SiO_2 wt%	0.02475	0.049962	0.075	0.1125	0.15	

Methodology

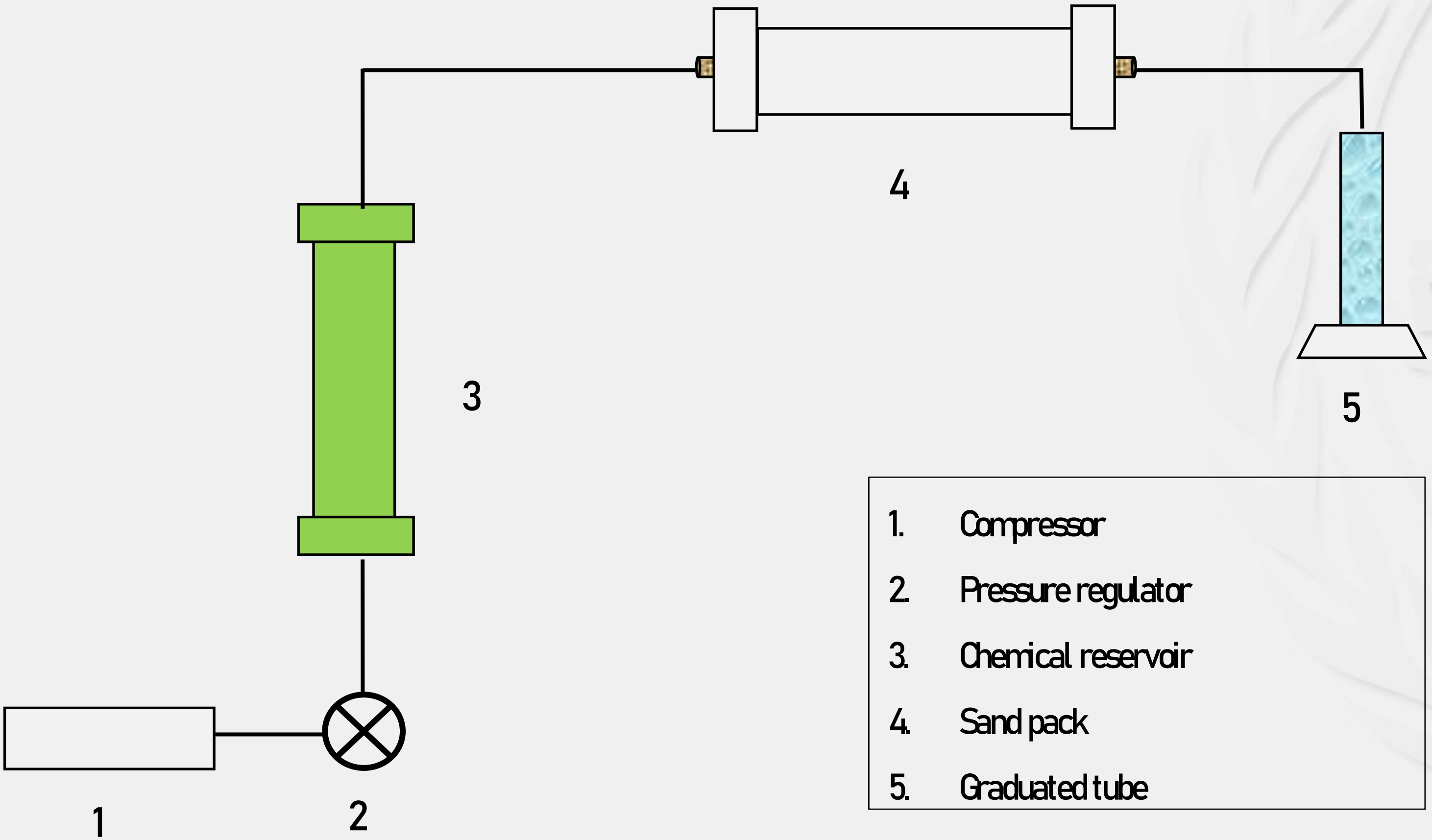


Figure 1. schematic diagram of the displacement apparatus

Table 3. Properties of the sand pack model, brine, formation water salinity used

Properties, unit	Values
Sand size, mm	$600\ \mu.m \le$ sand size $< 700\ \mu.m$
Length, cm	27.5
Diameter, cm	5
Area, cm^2	19.635
Bulk volume, cc	587
Pore volume, cc	160
Porosity, %	27.2572402
Permeability, mD	688.697398
Formation Water Salinity	150,000
Injected Brine Salinity	35,000

Methodology

3. Solution preparation

1. **Design Matrix Generation**: Use Design Expert software to generate chemical concentrations for flooding.
2. **Polymer Preparation**
   a. Weigh the required amount of polymer using a high-precision sensitive balance.
   b. Add the polymer to saline water with 35,000 ppm salinity (using NaCl).
   c. Mix the solution using a stirrer.
3. **Preparation Timing**: Prepare chemical solutions right before flooding to avoid air exposure and precipitation.
4. **Nano Solutions Handling**: Keep nano solutions on the stirrer continuously during the flood to maintain solubility.

Methodology

4. Displacement procedures

1. **Sand Pack Saturation:** Fully saturate the sand pack with brine.
2. **Initial Permeability Assessment:** Introduce brine to the saturated sand pack to assess permeability.
3. **Reservoir Initiation**
   a. Inject oil to displace the brine.
   b. Collect the oil effluent to determine the amount of oil displacing the brine.
4. **Water Flooding Process**
   a. Reintroduce brine to displace the oil in the sand pack model.
   b. Collect new oil samples over time, while maintaining pressure and flow rate.
5. **Repeated Steps for Different Fluids**
   a. Repeat the process for polymer, nano, and combined floods.
   b. Change only the displacing fluid in the oil displacement phase for each repetition.

Methodology

5. The interfacial tension measurement (IFT)

The IFT calculations were carried out using EZTensiometer surface tension calculation software by entering the maximum balance reading obtained from the EZTensiometer by ROD device and recording the interfacial tension measurement.

Results

1. IFT measurement:

Table 4. Measurements of the IFT of polymers and nano used.

	Chemical concentration	IFT mN/m
Xanthan Gum	500 ppm	28.151
	747.5 ppm	24.65
	1002.5 ppm	17.671
	1250 ppm	22.263
	1625 ppm	19.607
	2000 ppm	17.353
HPAM	500 ppm	75.342
	747.5 ppm	41.465
	1002.5 ppm	40
	1250 ppm	35.798
	1625 ppm	31.746
	2000 ppm	23.279
Nano silica (Silicon Dioxide SiO_2)	0.02475 wt%	28.385
	0.049969196778602 wt%	14.564
	0.075 wt%	10.789
	0.1125 wt%	4.82939
	0.15 wt%	19.0236

Results

2. Wettability determination

2.1. Xanthan gum polymer flooding wettability

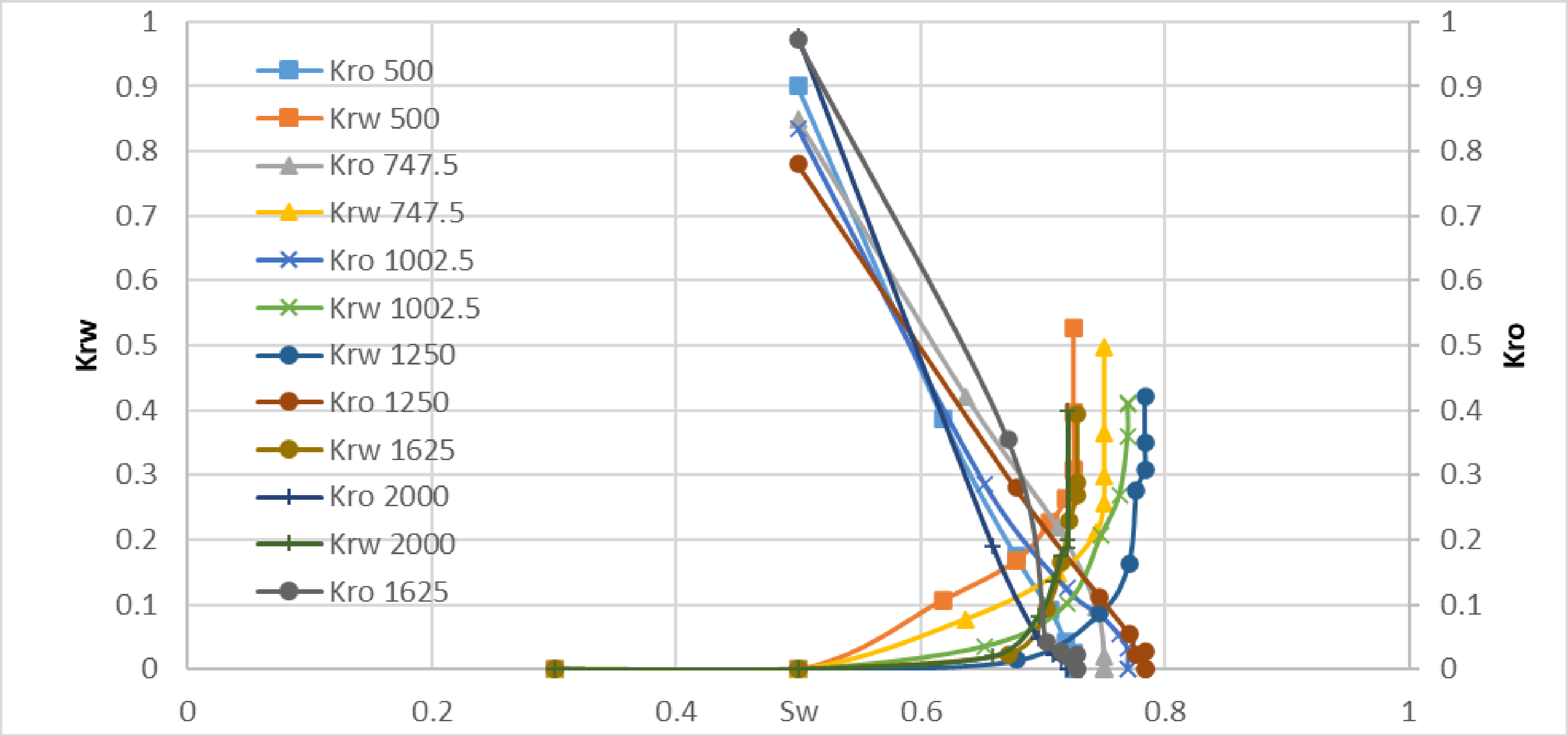


Figure 2. Relative permeability saturation curve for Xanthan-gum

Results

2. Wettability determination

2.2. HPAM polymer flooding wettability

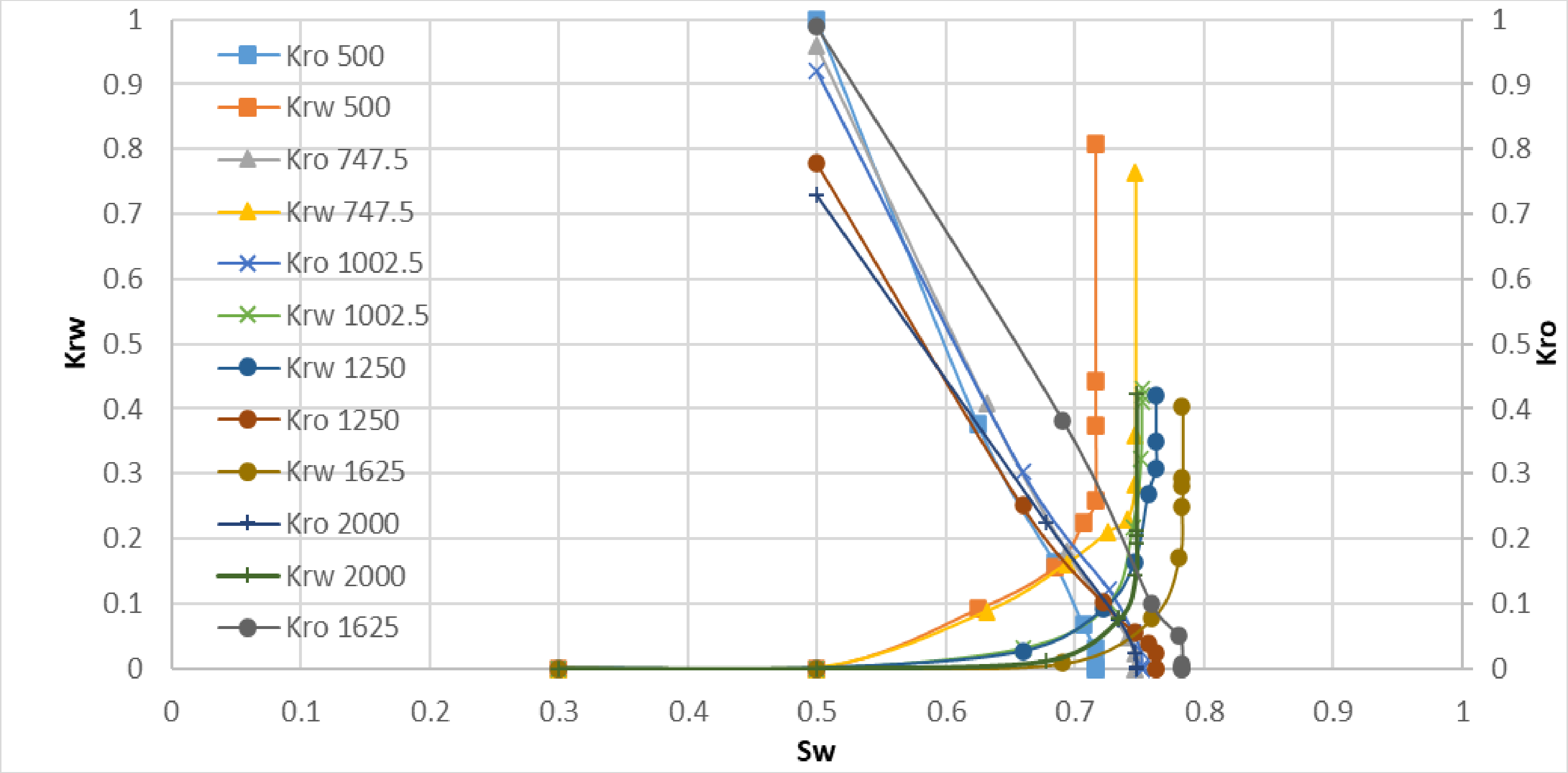


Figure 3. Relative permeability saturation curve for HPAM

Results

2. Wettability determination

2.3. Silicon dioxide nano flooding wettability

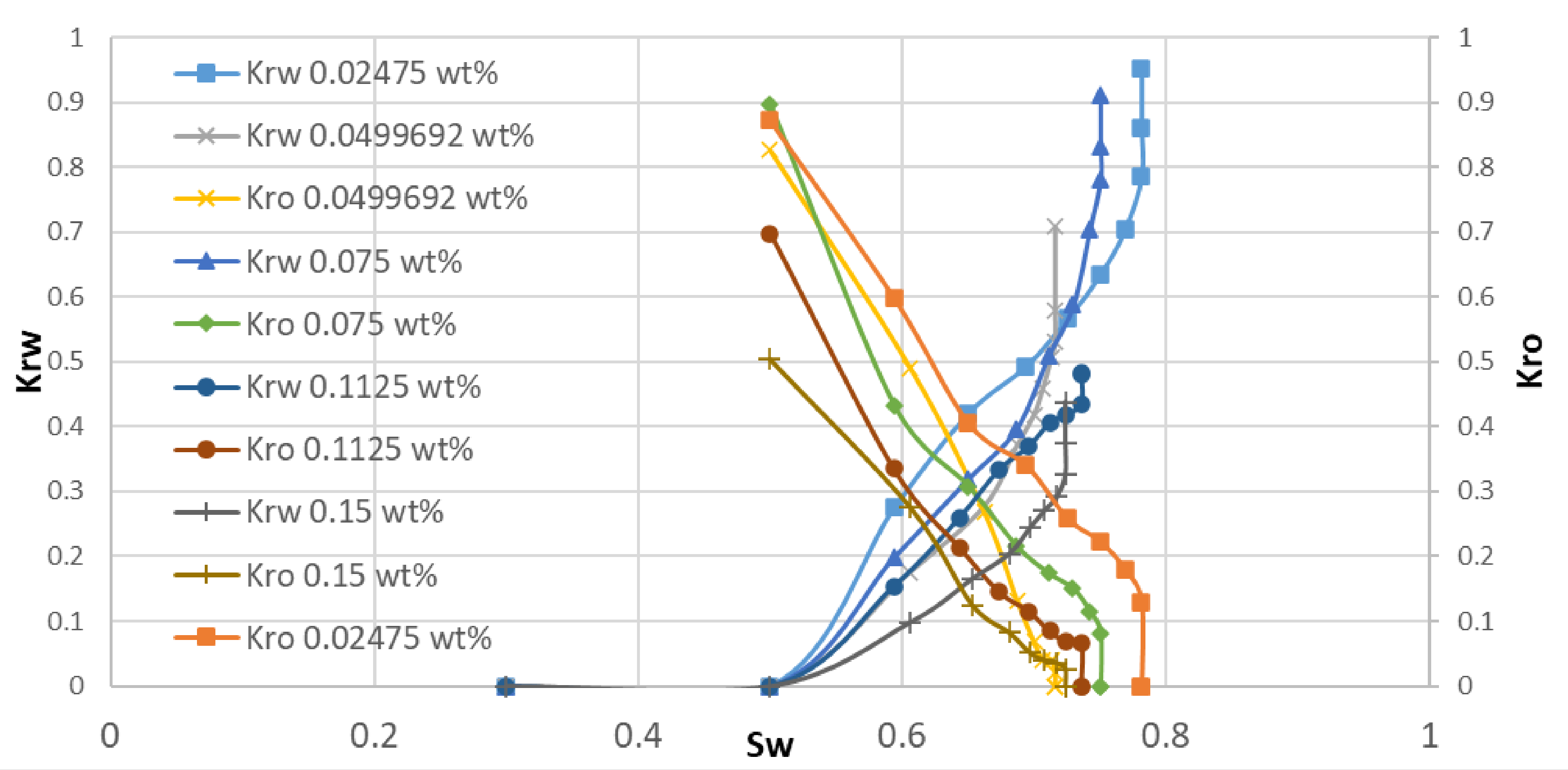


Figure 4. Relative permeability saturation curve for Silicon dioxide

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Results

2. Wettability determination

2.4. Nanosilica-polymer combined flooding wettability

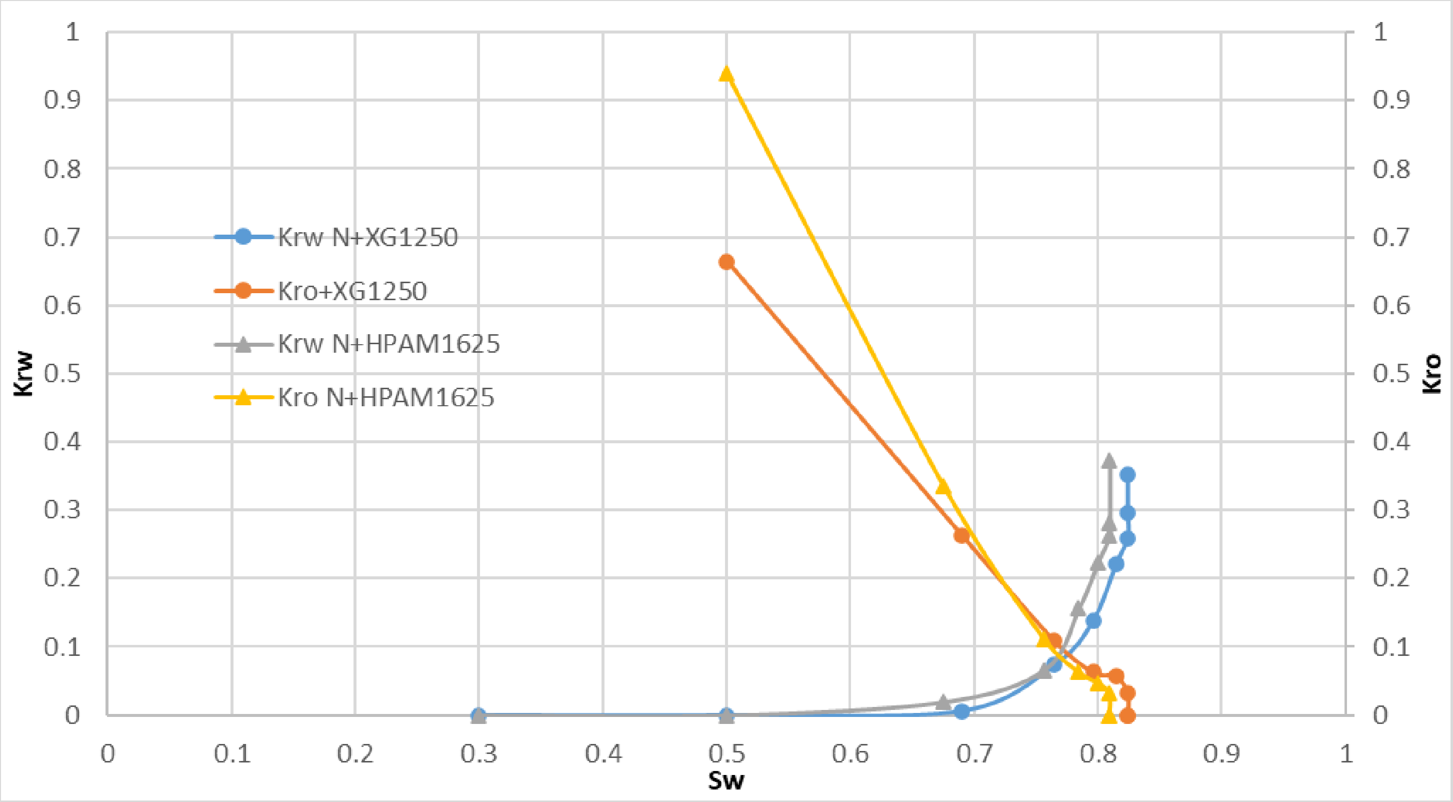

Figure 4. Relative permeability saturation curve for Nanosilica-polymer combined

Results

Table 5. Summary of Swi @ Krw=Kro

	Chemical concentration	S_{wi} @ $K_{rw}=K_{ro}$
Brine with 35,000 ppm		0.597
Xanthan Gum	500 ppm	0.679
	747.5 ppm	0.727
	1002.5 ppm	0.728
	1250 ppm	**0.751**
	1625 ppm	0.681
	2000 ppm	0.69
HPAM	500 ppm	0.681
	747.5 ppm	0.699
	1002.5 ppm	0.7265
	1250 ppm	0.727
	1625 ppm	**0.746**
	2000 ppm	0.732
Nano silica (Silicon Dioxide SiO_2)	**0.02475 Wt%**	**0.641**
	0.075 Wt%	0.65
	0.1125 Wt%	0.612
	0.15 Wt%	0.645
	0.049969196778602 Wt%	0.66
SiO_2 (0.02475 Wt%) +XG1250		0.778
SiO_2 (0.02475 Wt%) + HPAM1625		0.769

Results 3. Oil recovery

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	Chemical concentration	Recovered Oil (%)
Brine with 35,000 ppm		46.786
Xanthan Gum	500 ppm	60.714
	747.5 ppm	64.375
	1002.5 ppm	67.143
	1250 ppm	**69.107**
	1625 ppm	61.1607
	2000 ppm	60.122
HPAM	500 ppm	59.4643
	747.5 ppm	63.83928571
	1002.5 ppm	64.55357143
	1250 ppm	66.16071429
	1625 ppm	**69.01785714**
	2000 ppm	63.88098214
Nano silica (Silicon Dioxide SiO_2)	**0.02475 Wt%**	**68.75**
	0.075 Wt%	64.2857143
	0.1125 Wt%	62.3214286
	0.15 Wt%	60.5357143
	0.049969196778602 Wt%	59.4642857
SiO2 (0.02475 Wt%) +XG1250		**74.875**
SiO_2 (0.02475 Wt%) + HPAM1625		72.76785714

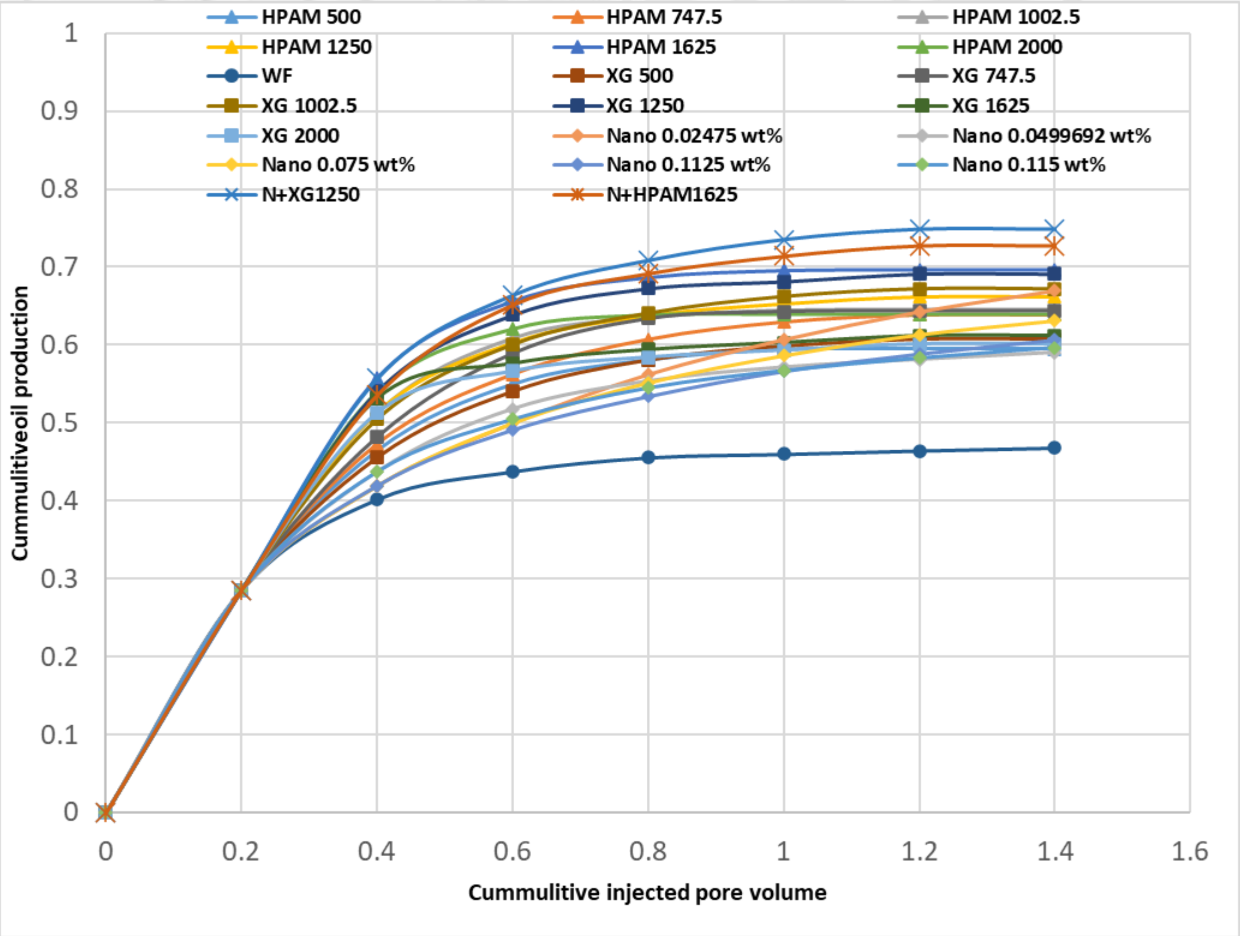

Figure 5. Relative permeability saturation curve for Nanosilica-polymer combined

Conclusion

- Xanthan gum was found to be the best polymer to be used as it gave the highest oil recovery at 1250 ppm.
- By adding the optimum nano concentration to the optimum polymer concentrations, the wettability was shifted from 0.746 in the HPAM flood to 0.769 and in the XG from 0.751 to 0.778 which led to a significant increase in the oil recovery.
- The oil recovery increases with the increase of the Xanthan-Gum concentration until it reached its peak at XG-concentration of 1250 ppm (69.107%) and for HPAM it reached its peak at the HPAM concentration of 1625 ppm (69.018%) and started to decrease again due to the adsorption effect.
- The oil recovery was at its best when combining the optimum nano-silica concentration (0.02475 wt%) with the optimum Xanthan-gum concentration (1250 ppm) and the optimum HPAM concentration (1625 ppm) to maximize the oil recovery (74.875%).

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