WATER STANDARD

EOR Water Management – Global Survey of Sourcing, Treating and Produced Water Reinjection

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REDEFINING WATER TREATMENT FOR THE OIL AND GAS INDUSTRY

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QUALITY SYSTEM CERTIFICATION ISO 9001:2008 DNV

Overview

- Growing popularity of water-based enhanced oil recovery (EOR) techniques impacts the water footprint of the oil and gas industry
  - Low Salinity Flooding (LSF)
  - Chemical EOR (CEOR)
  - Steam Flooding
- As a first step in disseminating the current body of knowledge of water usage and treatment in EOR applications, a survey was conducted in 2012 in conjunction with the Produced Water Society of water-based EOR projects to ascertain water source and water treating technologies. The study was updated in 2014.
- This presentation will describe the survey results which detail water-based data from 60+ EOR projects worldwide, along with a critique of the emerging technologies being piloted in global EOR field sites.

Enhanced Oil Recovery

Introduction

- There is a general trend in the oil and gas industry toward increased application of improved oil recovery (IOR) and EOR techniques.
  - Accelerates production and increases recovery of original oil in place (OOIP) over the life of a field, increasing value of the reservoir
  - Increased cost of finding new reserves
  - Obtain more oil where it has already been found
  - Significant fraction of world oil production comes from mature fields
  - Number of fields with moderate to high viscosity oils that have become viable by IOR/EOR techniques with recent sustained oil prices
  - Environmental regulations on feed water for injection and produced water disposal or re-injection

Introduction

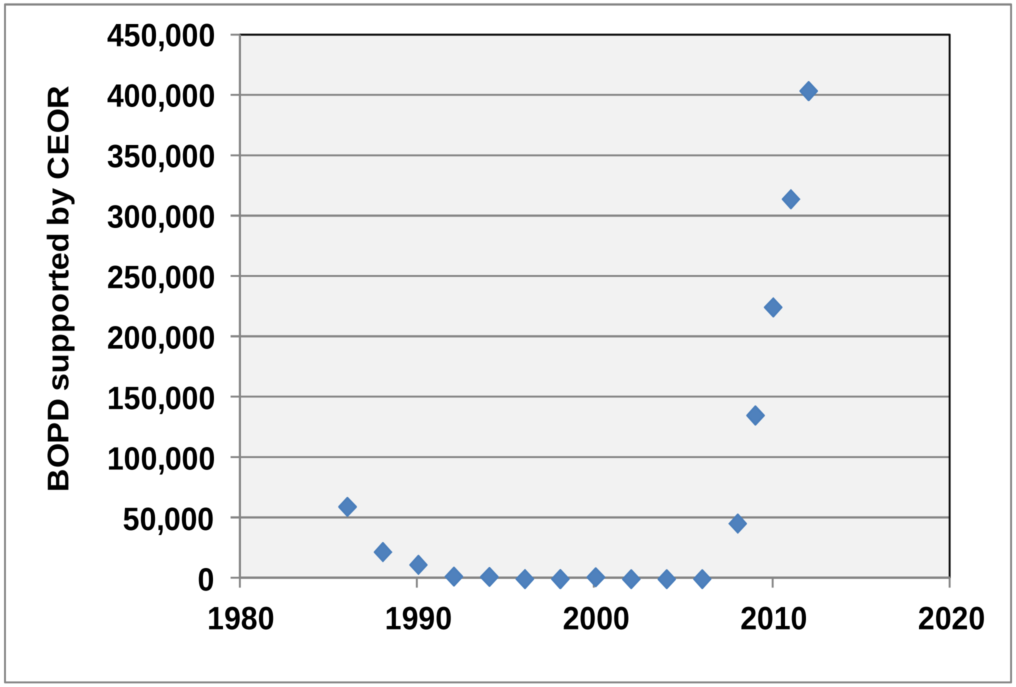
- Roughly 3.6% of current worldwide oil production is estimated to be from fields that utilize some form of EOR technique.

Current World-Wide Production Supported by EOR			
EOR Total	3 MM BOPD	3.6% of total world-wide production	
Thermal (including Steam)	1.2 MM BOPD	1.4% worldwide	40% EOR
Miscible Gas (including CO_2)	1.4 MM BOPD	1.7% worldwide	47% EOR
CEOR	0.4 MM BOPD	0.5% worldwide	13% EOR

- In the US, the current recovery rate from oil reservoirs is roughly 33%.
- If this value were to increase to 43% through the application of EOR techniques, it is estimated that an additional 45 billion barrels of oil could be produced from currently known oilfields [in the US].

Chemical Enhanced Oil Recovery (CEOR)

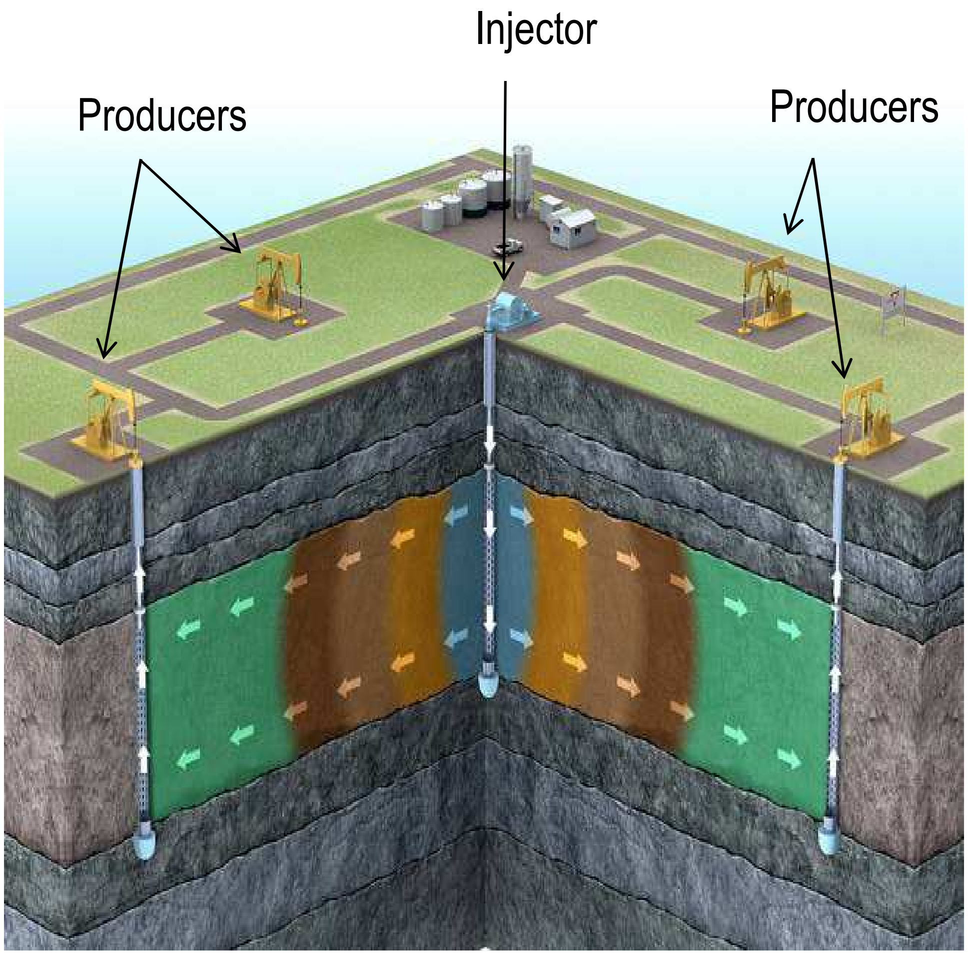
- Roughly 400 M BOPD are currently estimated to be produced from polymer and Alkali Surfactant Polymer (ASP) fields
  - Use of CEOR peaked in 1986 and declined with oil price collapse
  - As oil fields mature and oil prices are sustained, CEOR is being reconsidered
  - Studies indicate that the ultimate recovery (UR) of CEOR floods range from 0% to 30% of OOIP in the field



Source: Walsh, Henthorne, ATCE 2012, Water Treating Challenges in CEOR

CEOR Process

- Alkali:
  - Reacts with oil to produce natural surfactants (saponification)
  - Reduces surfactant absorption
- Surfactants:
  - Reduce interfacial tension between oil and water
  - Mix with polymers to contact additional oil in reservoir
  - Mobilize oil
  - Reduce oil content remaining in reservoir rock
- Polymers:
  - Increase viscosity of injected water
  - Divert water from high permeability zones to aid additional oil recovery
  - Improve sweep efficiency

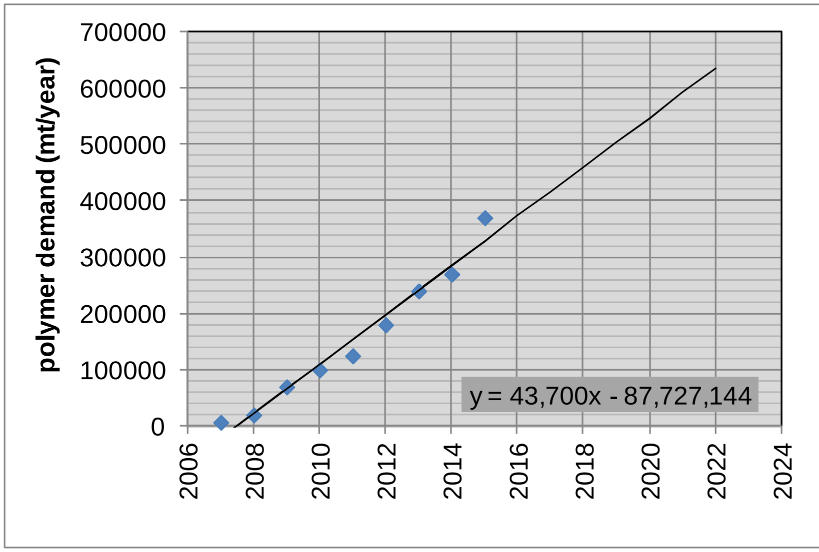


CEOR Gaining Momentum

- In fields where CEOR has been practiced, encouraging results have been obtained
- Improved understanding of water/chemical/reservoir interaction has been developed as a result of piloting, reducing the uncertainty and risk in reservoir response
- Regional oil companies are readily adopting CEOR for aging fields to continue to be economically productive
- Polymer flood requires less capital expenditure, compared to SAGD, and is therefore an attractive alternative for moderate viscosity (10 to 100 cP) oil
- **Hydrolyzed Polyacrylimide (HPAM) (polymer) cost reduction:**

1986	16	USD/kg polymer per USD/kg oil
2014	3	USD/kg polymer per USD/kg oil

Estimated Oil Production Supported by Polymer



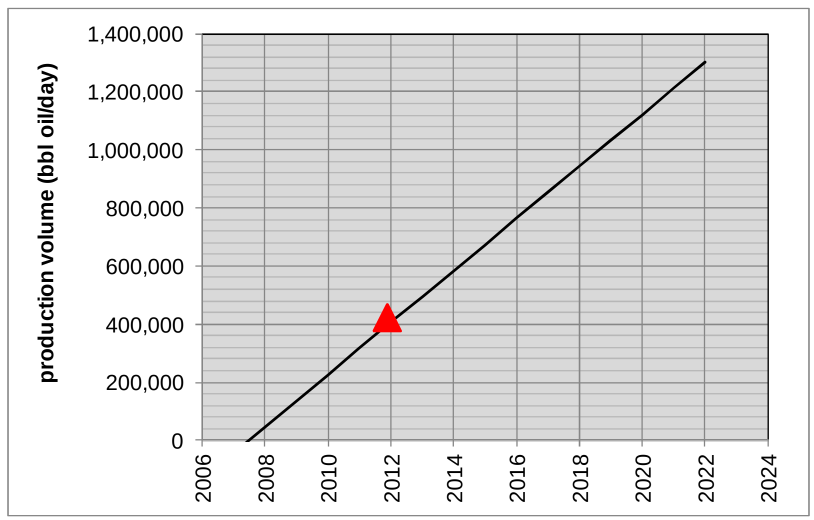
Polymer sales volumes and projections for a major polymer supplier

World-wide total polymer demand (454 MT/year), Pope, JPT (July 2011)

Source: Walsh, Henthorne, ATCE 2012, Water Treating Challenges in CEOR

Oil production volumes estimated by assuming values for polymer concentration, water injection/oil production ratio, and China volumes, etc.

▲ Current production estimate (400 kBOPD)



Water Treating Challenges in CEOR

- Significant water treating challenges occur both on the injection side and the back-produced side of projects.
- For both onshore and offshore projects, low salinity requirements of the injection water and the chemical and oil content of back-produced water are challenging.
  - Injection water and ionic composition
  - Divalent cation concentration depending on the clay concentration and type
  - Salinity and sulphate content
- Produced water and the presence of CEOR chemicals
  - Higher oil concentrations
  - Smaller oil drops
  - Increased jetting of bubbles in a flotation unit

Effect of Polymer on Separation Efficiency

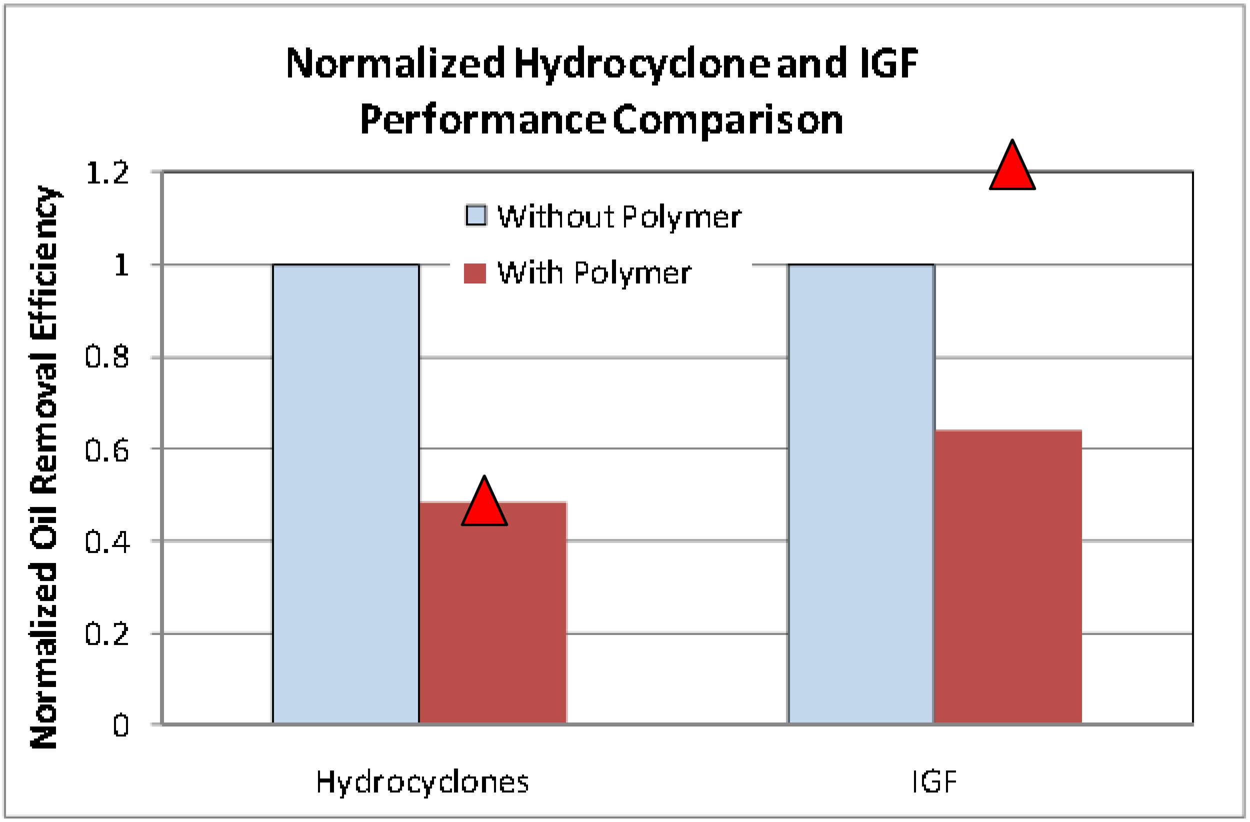


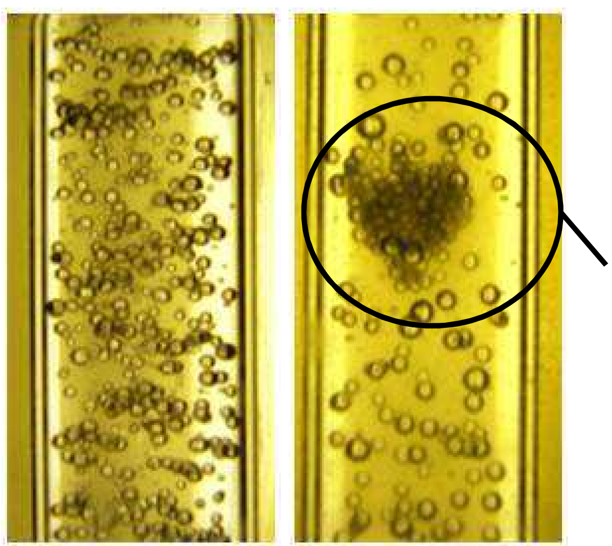
Figure 6. The impact of HPAM on the oil removal efficiency of hydrocyclones and IGF

▲ Conventional modeling taking into account viscosity but not the non-Newtonian rheology of polymer solutions

Data from SPE 144322 Zheng, Quiroga, Sams (2011), modeling: unpublished

Effect of Polymer on Flotation Bubble Distribution

With Polymer

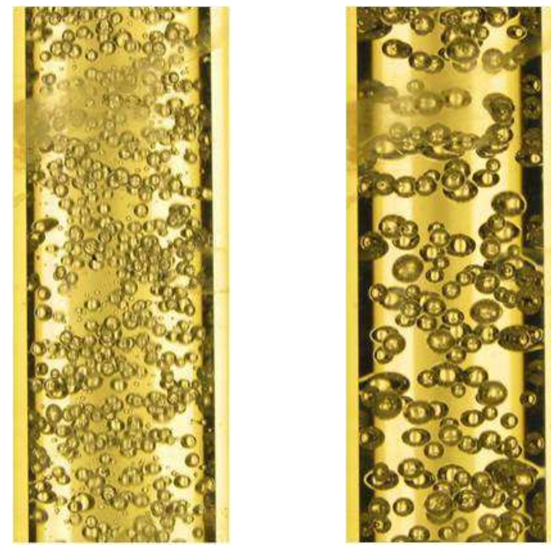


bubbles cluster and rise rapidly

3.5 mPa.s   8 mPa.s

Non-uniform bubble distribution.

Without Polymer
Viscosity increase using glycol



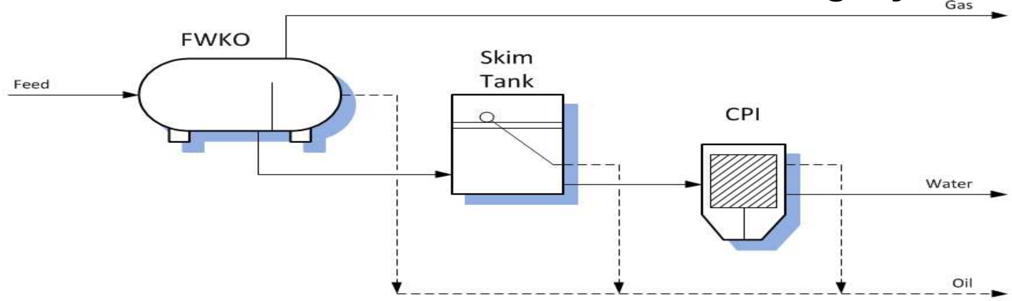
1 mPa.s   16 mPa.s

Uniform bubble distribution. Bubbles rise slower with higher water viscosity

- Non-Newtonian nature of polymer solution causes bubble jetting and clustering which causes rapid bubble rise velocity, bubble clustering, and secondary flow patterns. This reduces the oil drop capture efficiency and leads to poor separation efficiency

Increased Treatment Requirements

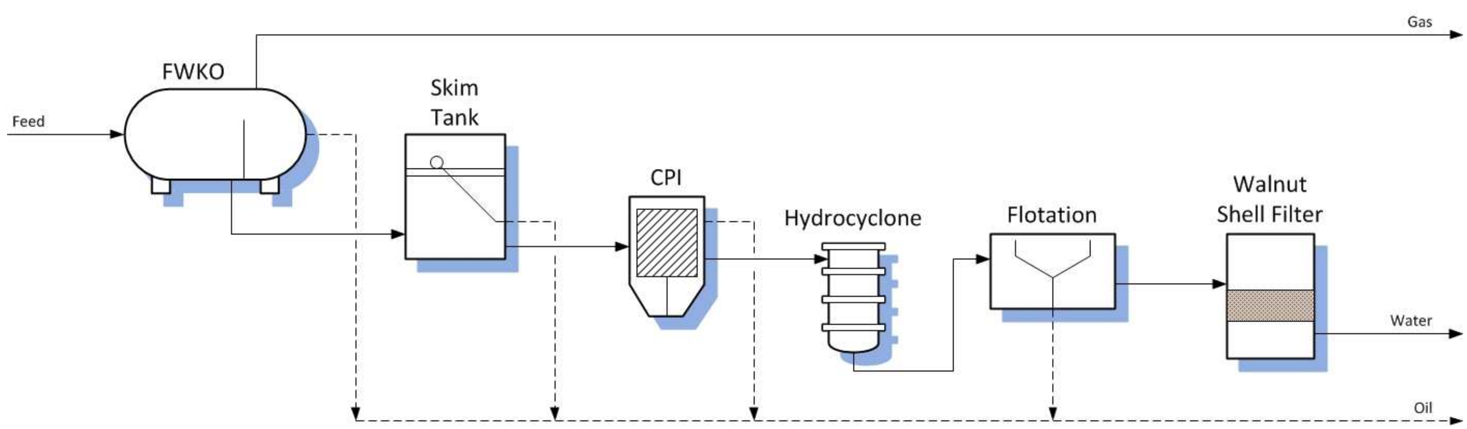
Conventional Onshore Produced Water Treating System – No Polymer



Conventional System: without polymer (0.7 cP) – 4 hour Skim Tank Design
with polymer (2 cP) – 12 hours required

As a result of polymer present in the produced water, conventional process treatment needs to be intensified to successfully deal with the polymer in the water.

Polymer Backflow Onshore – Process Intensification



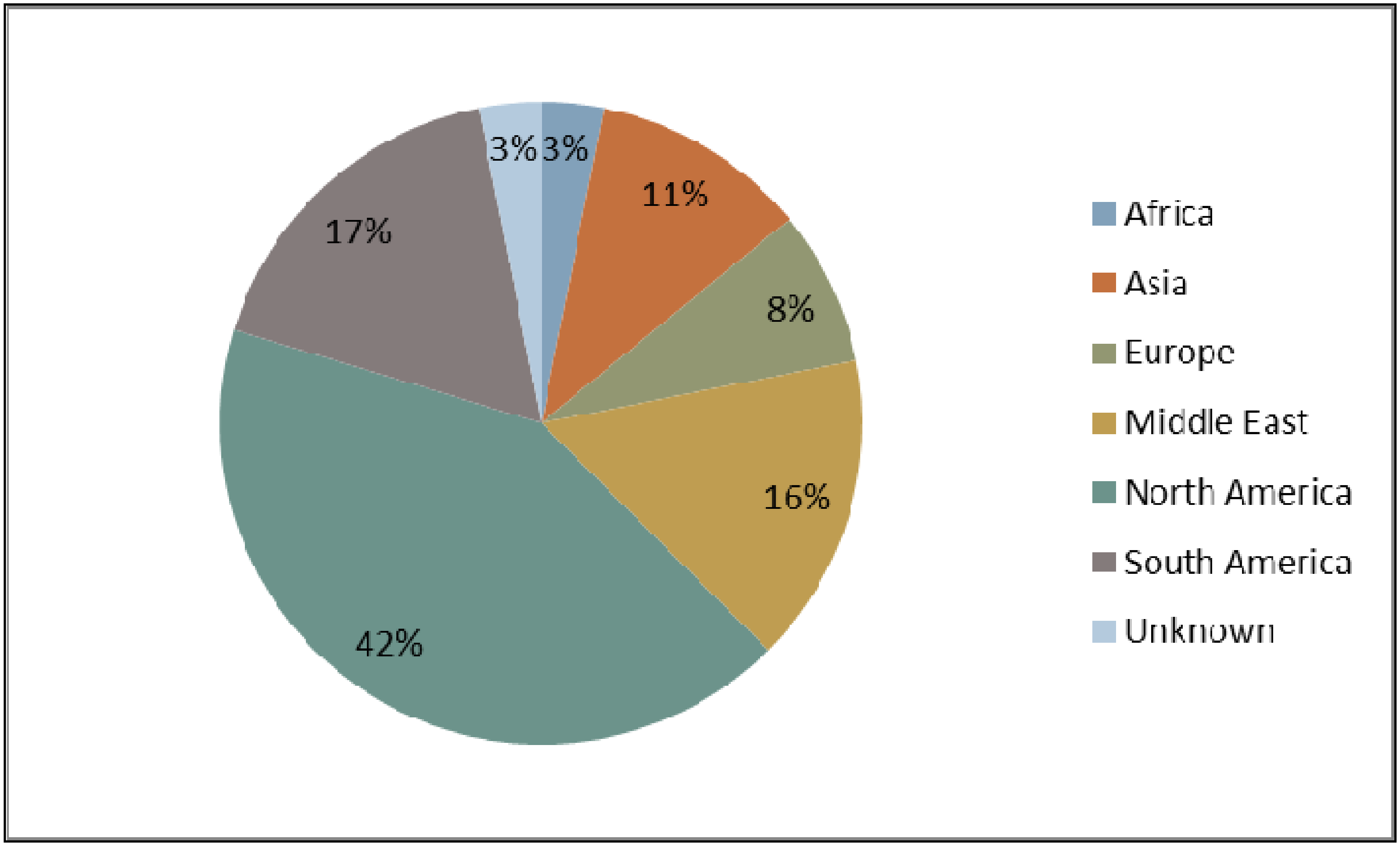
Results

Background

- A survey in partnership with the Produced Water Society took place in 2012
  - Objective: assess the current produced water treatment technology methods used in water-based EOR
  - Targeted a broad audience
  - Designed to gather data on water treatment methods presently being used in active water-based EOR projects worldwide
- Survey results were augmented in 2014 through literature and industry research for both full scale EOR applications and emerging technology solutions being piloted

Results – Global Projects

- Number of Projects: 65
- The majority of EOR projects are located in North America
- Significant opportunities exist in South America and the Middle East



Identified Projects

Project Name	Location	Operator	Type of EOR
Projects Brown Field	Africa	Total	CEOR
Dalia	Africa	Total	P
Angsi Chemical Enhanced Oil Recovery	Asia	Petronas	ASP, P, SP
ANGSI CEOR	Asia	PETRONAS	ASP, SP
St. Joseph	Asia	Petronas	ASP
Rajasthan Onshore Block RJ-ON-90/1	Asia	Cairn	EOR
Rajasthan	Asia	ONGC	EOR
Kalol	Asia	-	ASP
Not Specified	Asia	PT Chevron Pacific	SP
Daqing	Asia	Daqing Oilfield	P, trials ASP
BP Clair Ridge	Europe	BP	Low Salinity Injection
Baku	Europe	BP	non-SAGD Steam
Skarv Development Project	Europe	BP	
Not Specified	Europe	-	Low Salinity Injection
Jasmine Development Project	Europe	ConocoPhillips	
Al Shaheen Low Salinity Project	Middle East	Maersk	Low Salinity Injection
PDO Marmul	Middle East	PDO	CEOR
confidential	Middle East	TOTAL	SP
Oman	Middle East	Shell	ASP, P, SP
Polymer flooding Marmul	Middle East	PDO	Polymer (HPAM)
Al Shaheen	Middle East	Maersk Oil	ASP, P, Microbial, Low Salinity Injection
Belayim Land	Middle East	Belayim Petroleum Company	P

Identified Projects

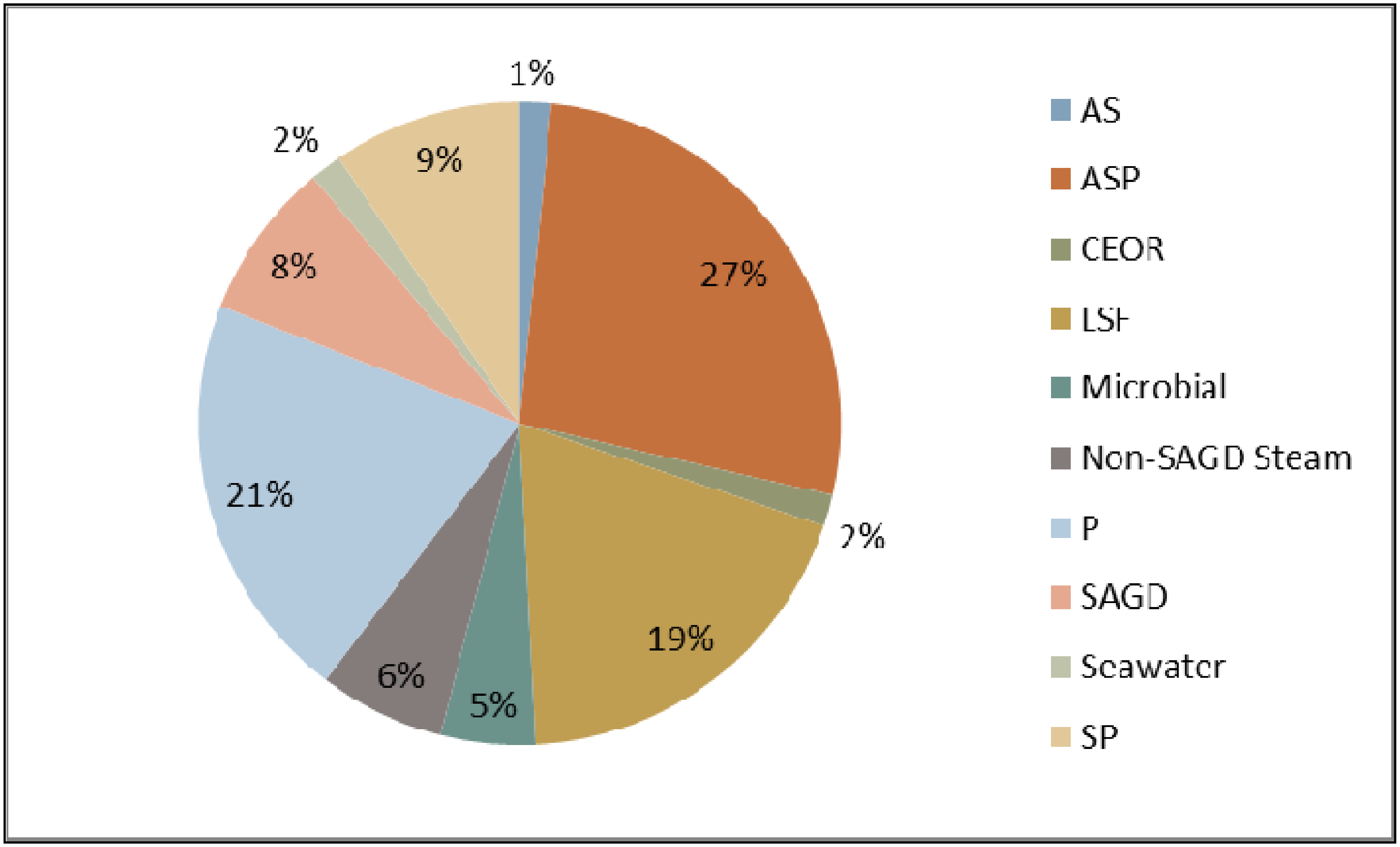
Project Name	Location	Operator	Type of EOR
Belayim	Middle East	PETROBEL	P
Abu Al-Bukhoosh	Middle East	Total	SP
HTHS EOR Project	Middle East	Total	SP
Water Injection	North America	Thunder Horse - BP	SeaWater
Not Specified	North America	-	SAGD, non-SAGD Steam
Battrum	North America	Hyak Energy	ASP
Trembley Oilfield	North America	-	ASP
Unknown	North America	Denbury Resources	non-SAGD Steam
Not Specified	North America	ConocoPhillips	SAGD
Husky Valhalla	North America	Husky Oil Operations Ltd	Microbial, Low Salinity Injection
Silo Field	North America	R360	SAGD
Confidential	North America	Confidential	Microbial
Cymric	North America	Chevron	non-SAGD Steam
Confidential	North America	ACS Medio Abiente	Low Salinity Injection
Confidential	North America	CONFIDENTIAL	Low Salinity Injection
Not Specified	North America	Cenovus	SAGD
ASP fooding pilot	North America	OXY	ASP
Grand Forks Pilot	North America	CNRL	ASP
Nipisi Pilot	North America	CNRL	P
Lone Rock Pilot	North America	CNRL	P
Little Bow	North America	Zargon	ASP
Lawrence Field - Delta	North America	Rex Energy	ASP

Identified Projects

Project Name	Location	Operator	Type of EOR
Unnamed Pilot	North America	-	SP
Endicott Field	North America	BP	LSI
Kuparuk	North America	ConocoPhillips	LSI
Mad Dog	North America	BP	LSI
Pelican Lake	North America	CNRL	P
Pelican Lake	North America	Encana	P
Saskatchewan	North America	Talisman	ASP
Thunderhorse	North America	BP	LSI
Peregrino Polymer Flooding Project	South America	Statoil	P
Proprietary	South America	Proprietary	SAGD
Peregrino, Brazil	South America	Statoil	Low Salinity Injection
ASP Colombia	South America	-	ASP
Dina Cretaceos	South America	Ecopetrol	ASP
Tello	South America	Ecopetrol	ASP
Yaguara	South America	Ecopetrol	ASP
San Francisco	South America	Ecopetrol	ASP
Cataumbo/Mid-Mag Pilot	South America	Ecopetrol	ASP
Orinoco Belt	South America	PDVSA	P
Meta Providence	South America	Williams Energy	CEOR
Mina	Unknown	Shell	CEOR
VicBilh	Unknown	Total	CEOR

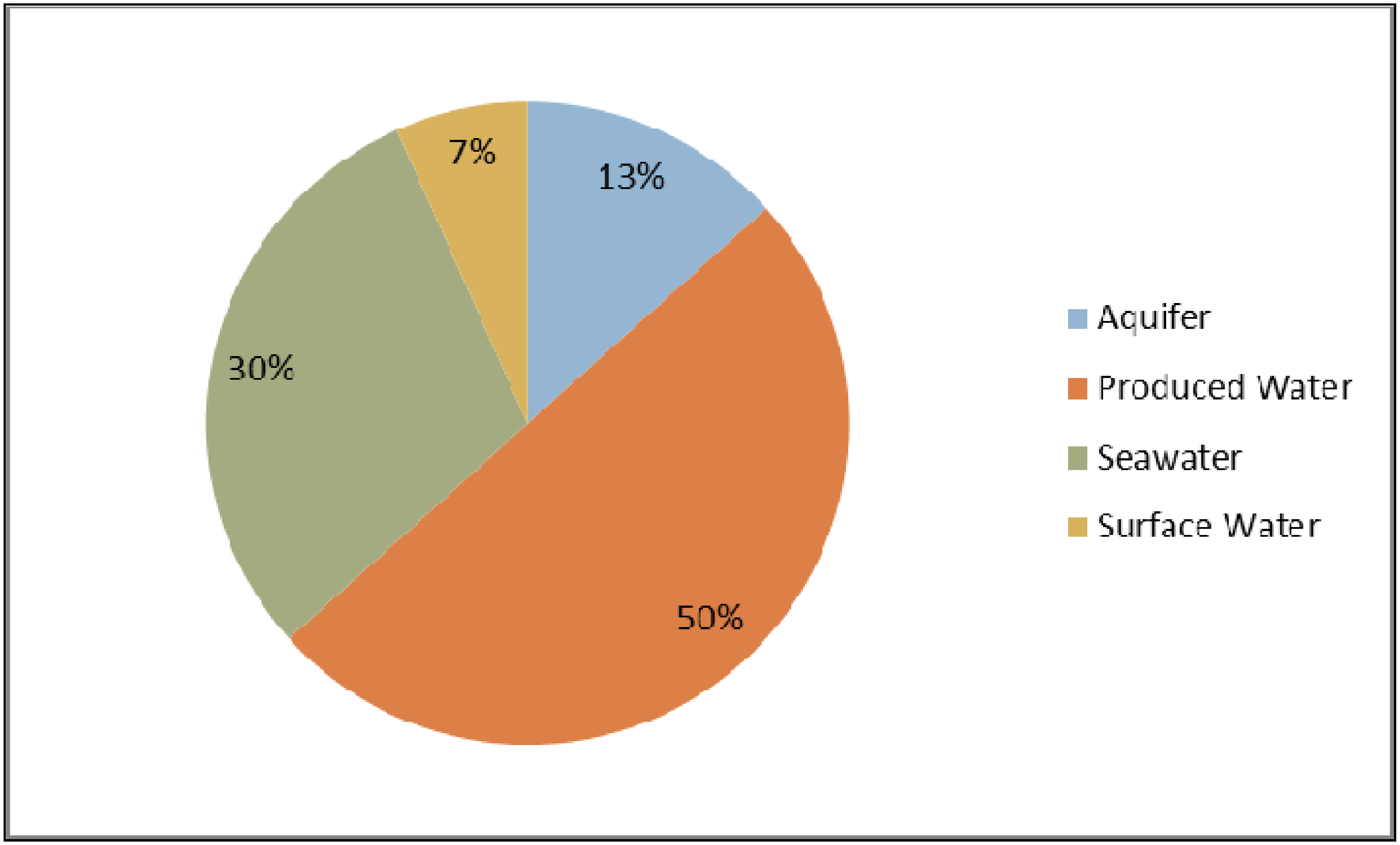
Type of EOR

- A wide range of EOR strategies are being implemented worldwide
- ASP flooding is the most widely-used strategy (27%)
- Many polymer flooding (21%) and LSF (19%) projects represented



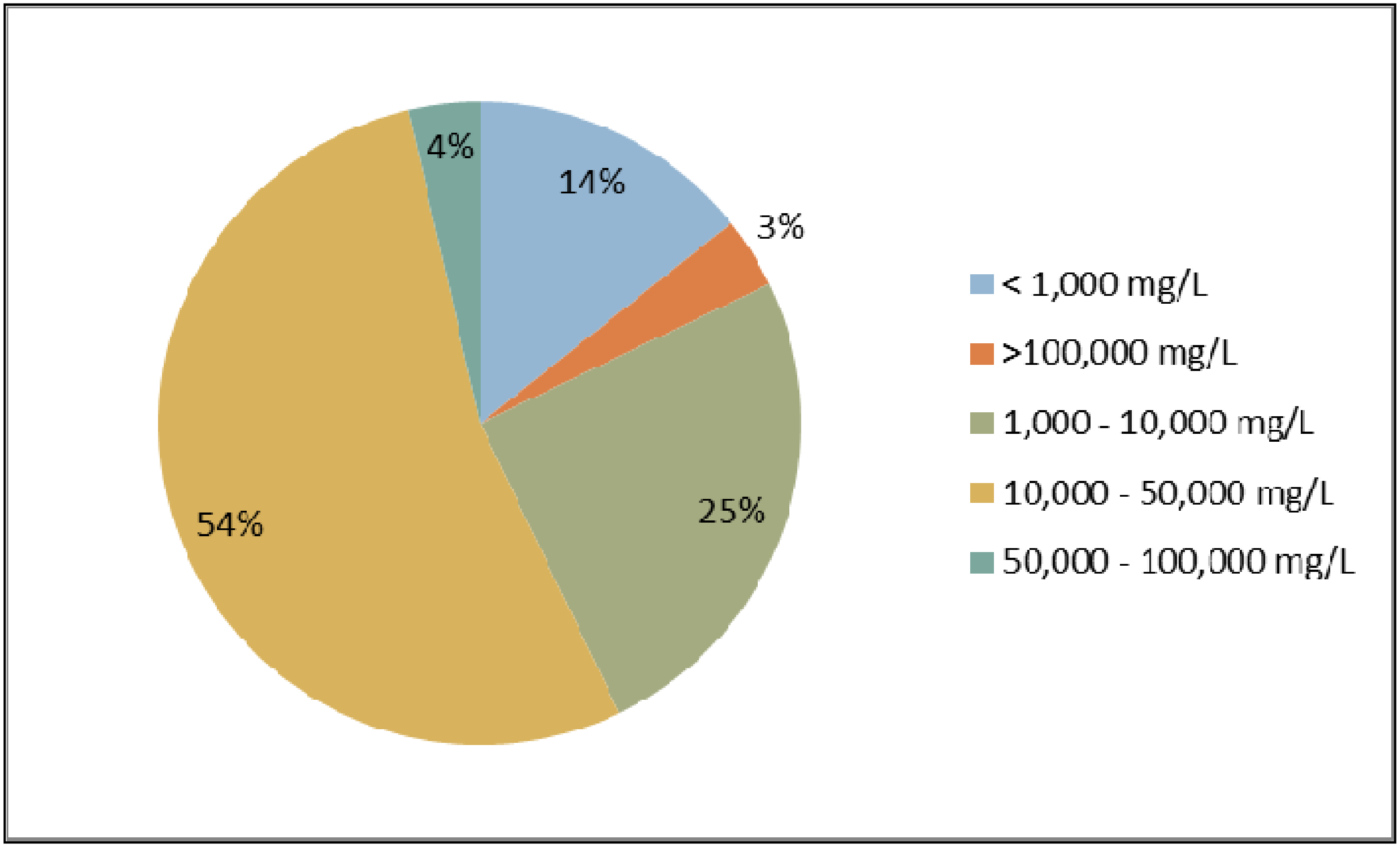
Type of Water Source

- Of projects for which the water source was specified, half use produced water as the primary injection fluid for EOR
- Seawater represents a significant EOR injection fluid source



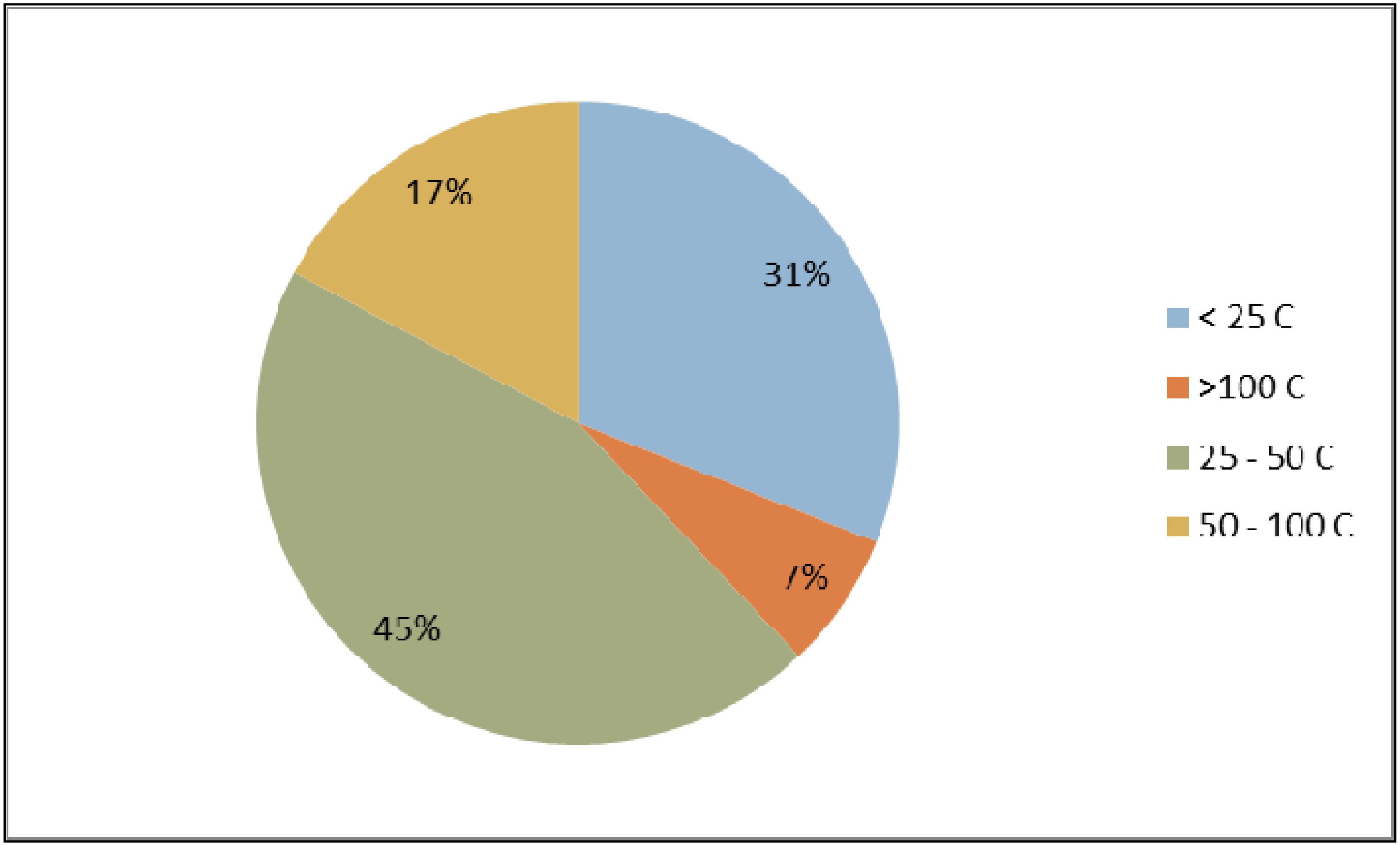
Source Water Salinity

- Of projects for which source water salinity was reported, most fluid sources are brackish or saline (54%)
- Highly saline water is used for EOR in numerous applications



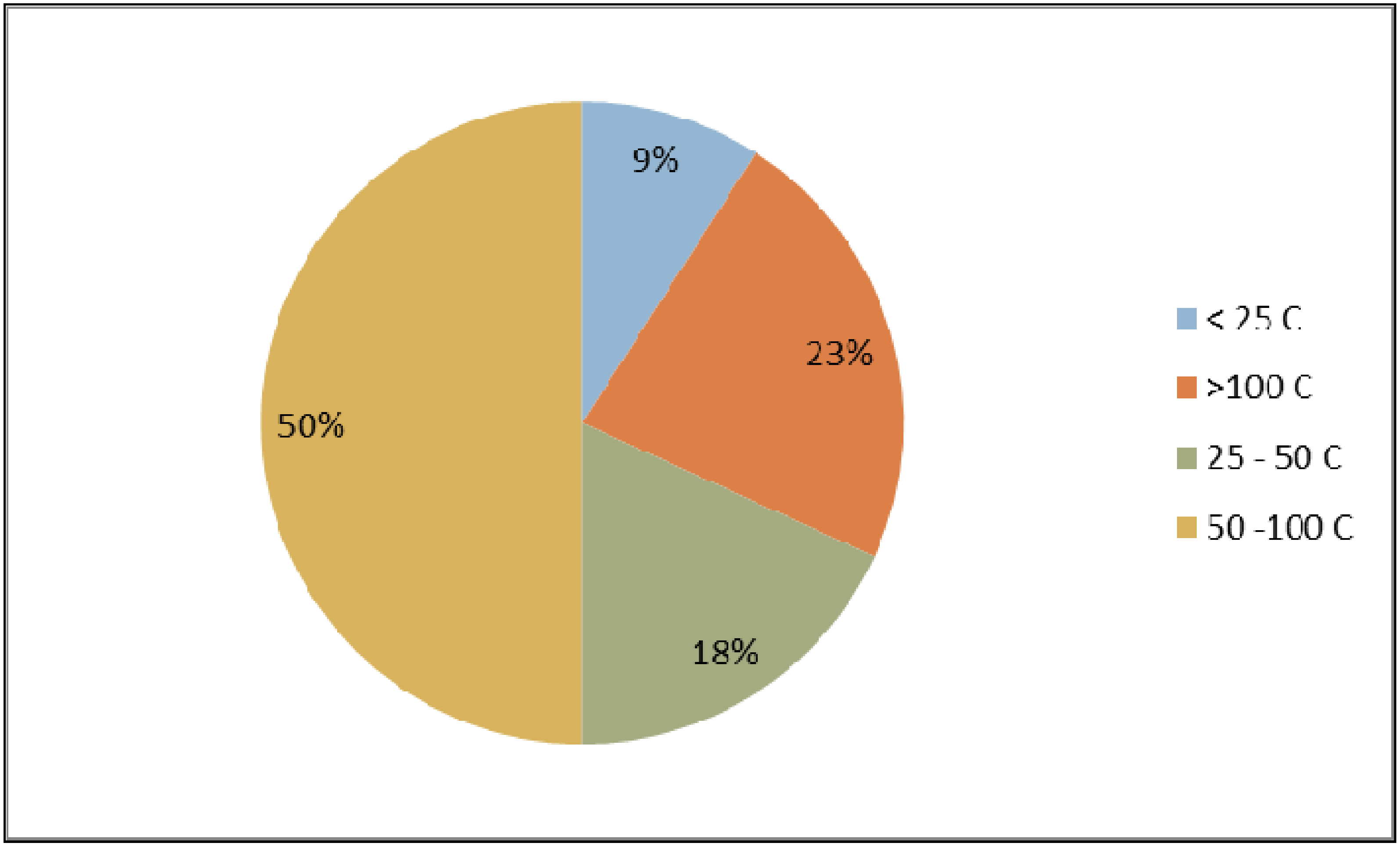
Source Water Temperature

- Of projects for which source water temperature was reported, most fluids are between 25 – 50°C



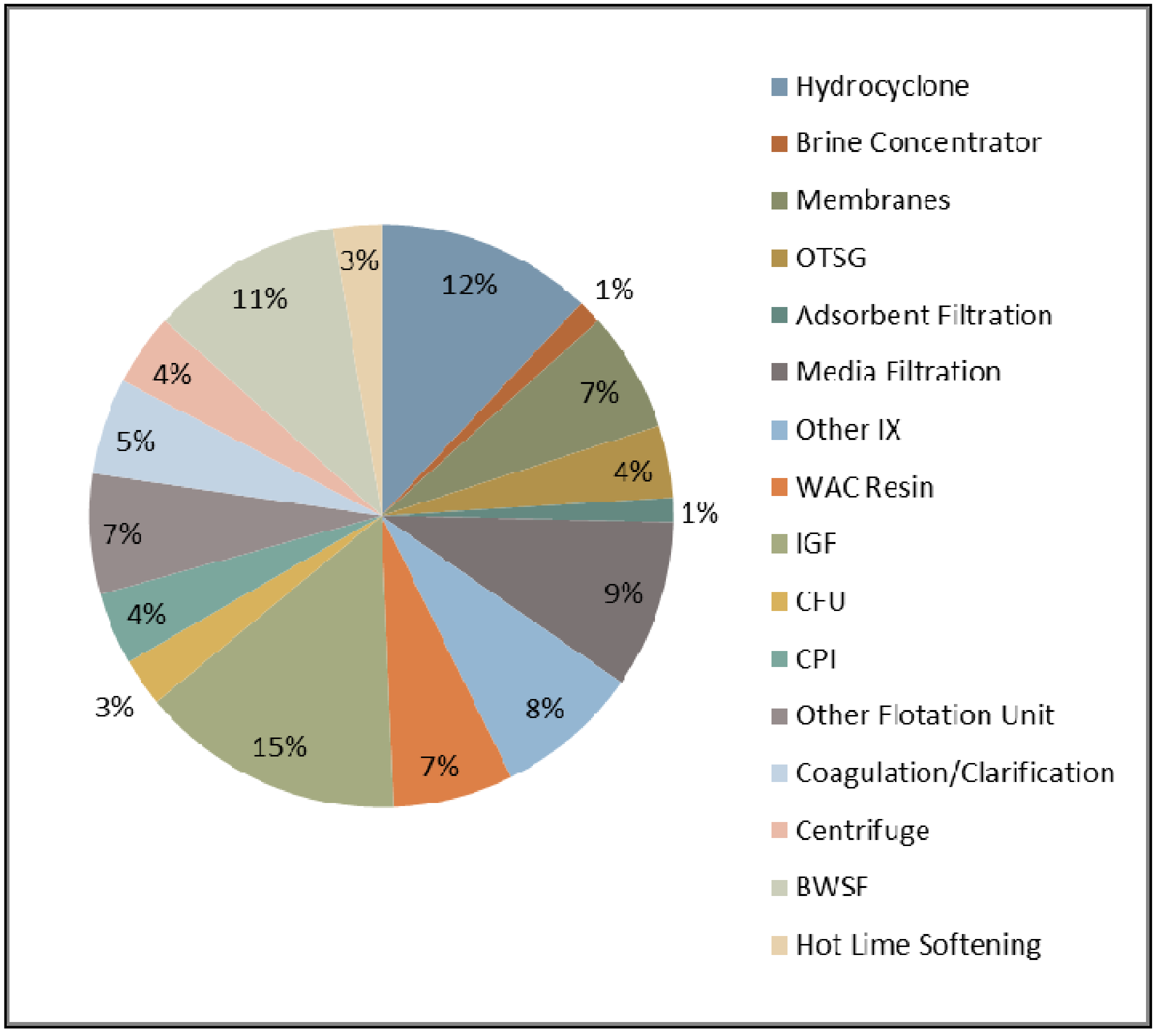
Reservoir Temperature

- Of projects for which reservoir temperature was reported, most target reservoirs are warm (i.e. between 50 – 100°C)



Produced Water Treatment Unit Operations

- Of projects for which produced water treatment unit operations were reported, a wide variety of technologies are being implemented
- IGF, hydrocyclones, and BWSF represent the most used technologies



Common Produced Water Treating Unit Operations

- Induced Gas Flotation (IGF)
  - Separation of oil and fine solid particles using attachment to induced gas bubbles to float contaminants to the surface
  - Impacted by polymer
- Hydrocyclone Technology
  - Separation of oil or solids from water using hydraulically-induced centrifugal forces from tangential input of feed
  - Impacted by polymer
- Black Walnut Shell Filter (BWSF)
  - Adsorption process which easily strips oil and contaminants from water
  - Resists fouling better than other media filters
  - CEOR chemicals not expected to impact performance

Conclusions

- Water Treating in EOR is Critical
  - Achieve desired water injection quality
  - Ensure back-produced waters are effectively treated
- Emerging Technologies
  - Primarily being applied in small facilities
  - Need to go through vetting and risk analysis
- CEOR Onshore Treatment
  - Dilution of polymer backflow with conventional produced water
  - Higher viscosity makes skim tank settling expensive
  - Process intensification via hydrocyclones, flotation, nutshell filters
- CEOR Offshore
  - Similar to onshore but will require more equipment, challenge to reduce footprint and weight
  - More efficient and targeted technologies needed

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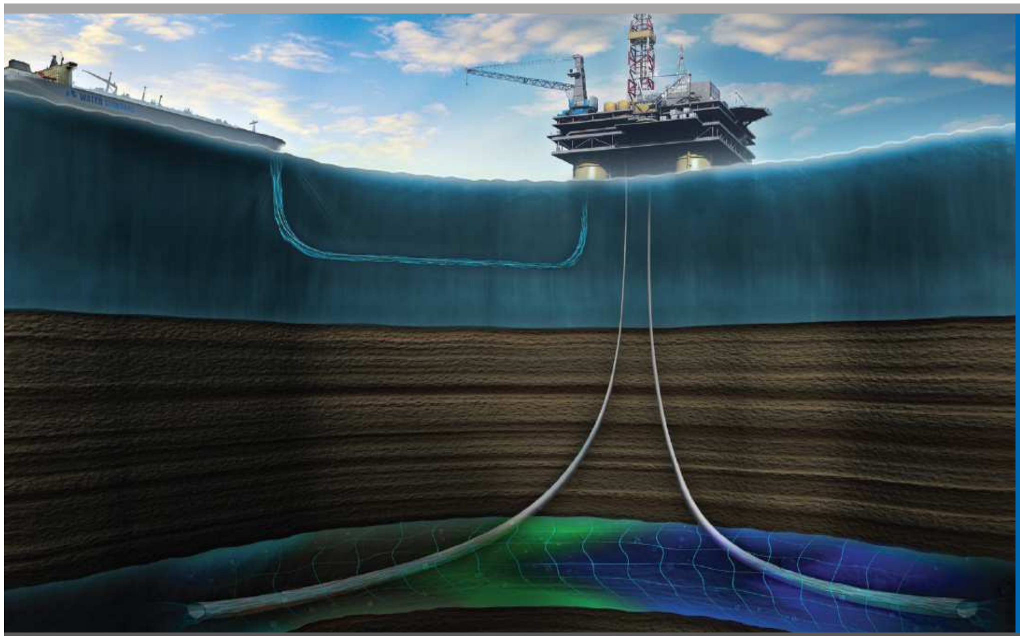

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