Experimental Investigation of WAG and CO_2 injection

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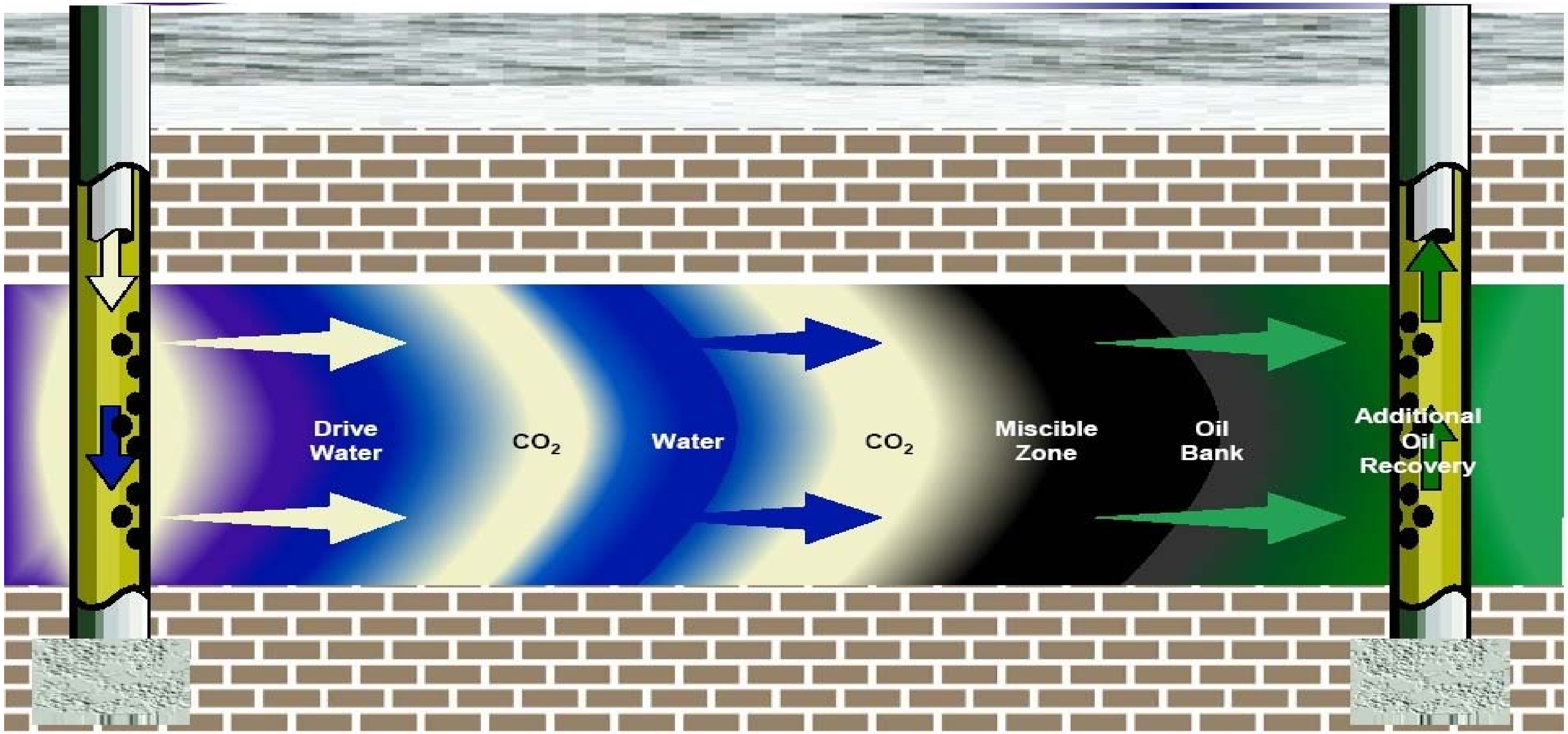
Topics of Discussion

- Introduction
- Theory of WAG
- Experimental Set-up
- Description & Results of Experiments
- Conclusion & Recommendation

Simply Stated



History of WAG

- Patented by Parrish in 1966

- Initially proposed as a method to increase the sweep efficiency during gas injection

- Field Trails
  - USA
  - UK
  - Russia
  - Norway
  - China
  - Venezuela
  - Canada

Classification of The WAG Process

- Miscible
- Immiscible
  - WASP
  - SWAG
  - Hybrid WAG
  - FWAG

Factors Affecting the WAG Injection Process

- Fluid properties
- Miscibility conditions
- Injection technique
- Rock wettability
- Reservoir heterogeneity

Operational Problems

- ❑ Early breakthrough in production wells
- ❑ Reduced Injectivity
- ❑ Corrosion
- ❑ Scale Formation
- ❑ Asphaltene & Hydrate Formation
- ❑ Different temperature of injected phases

WAG injection and its Advantage & Drawbacks

Advantage:

- WAG injection increase both microscopic & macroscopic efficiency.
- Mobility control
- Lesser gas consumption

Drawbacks:

- Operational problem
- Process complexity

Experimental Set-up

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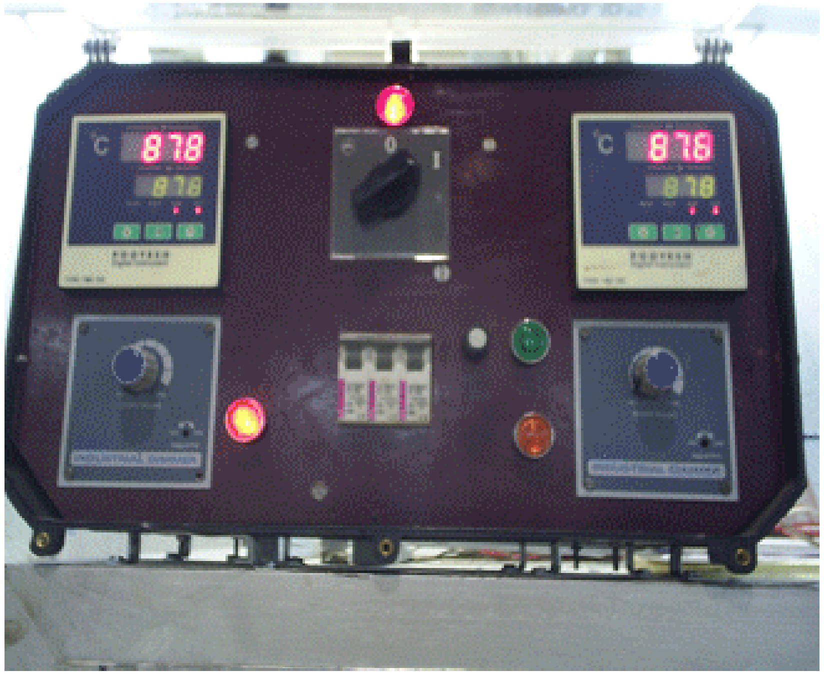
Thermostatic Bath & Temperature Controller Systems



Pumps

Injection Pump:

- ❑ HPLC Pump (Agilent 1200)
- ❑ HPLC Pump (Waters 515)

Pressurized Accumulators:

Air Driven Liquid Pump

Hydraulic Pump

Accumulators

Core Holder

Type	Length	Diameter
SP-I	34.56 cm	2.376 cm
Core	16.00 cm	3.81 cm

Back Pressure Regulator

Separator & Gas Meter

Experiments & Results

Dead Oil Analysis

NO.	Component	Mole %	NO.	Component	Mole %
1	C3	0.369	15	C15	1.534
2	iC4	0.618	16	C16	0.959
3	nC4	1.541	17	C17	0.477
4	iC5	2.167	18	C18	0.275
5	nC5	2.923	19	C19	0.139
6	C6	6.442	20	C20	0.106
7	C7	9.403	21	C21+	32.257
8	C8	11.694			
9	C9	10.589			
10	C10	5.815			
11	C11	4.549			
12	C12	2.962			
13	C13	3.013			
14	C14	2.168			

Oil Properties

Reservoir Pressure	3725 psi
Bubble Point Pressure	3650 psi
Average Molecular Weight	218.35 gm/gm.mol
Specific Gravity	0.8848

MMP Calculation

Dead Oil

Injection Gas	CMG Software	Correlations	
CO_2	7300 psi	Alston Correlation 3513.47 psi	
N_2	48114 psi	Hudgins Correlation 5567.63 psi	Firoozabadi & Aziz Correlation 8002.16

Live Oil

Injection Gas	CMG Software	Correlations	
CO_2	3941 psi	Alston Correlation 3735.39 psi	
N_2	8096 psi	Hudgins Correlation 5566.96 psi	Firoozabadi & Aziz Correlation 6372.25 psi

Steps of Experimental

- Water Saturation
- Brine Permeability
- Oil Saturation at atmospheric pressure
- Oil Saturation at injection pressure
- Injection
- Washing

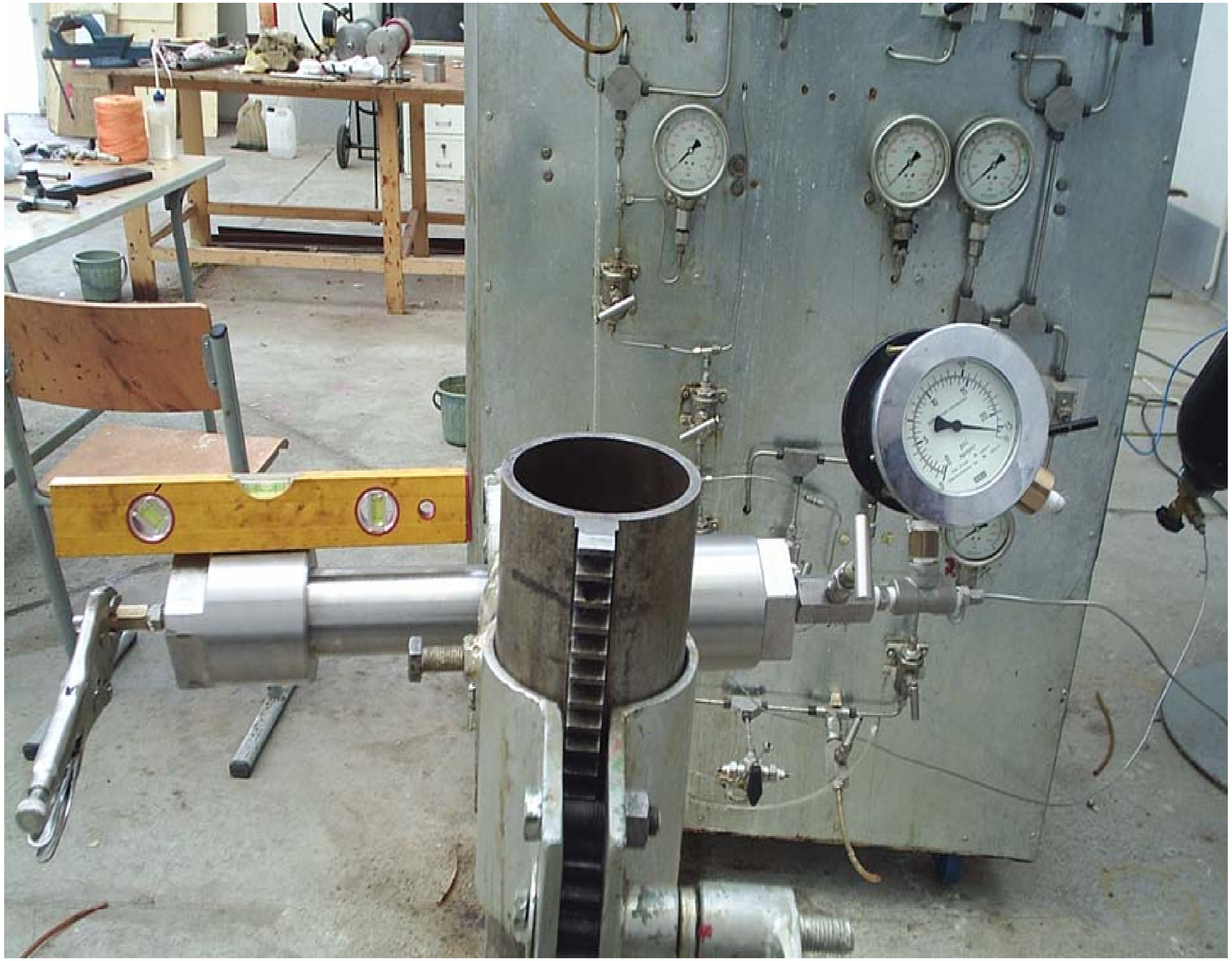
Experiments Description

Test	Process	Recovery Stage	Type of Model	Type of Oil	Type of Injection Water	P (psi)	T (C)	Q (cc/min)	Slug Size	WAG Ratio
1	CO_2 Injection	Secondary	SP-I	Live Oil	Brine	3800	87.8	0.1	1.2	---
2	CO_2 Injection	Secondary	SP-I	Live Oil	Brine	4200	87.8	0.1	1.2	---
3	CO_2 Injection	Secondary	SP-I	Live Oil	Brine	4600	87.8	0.1	1.2	---
4	CO_2 Injection	Secondary	SP-I	Live Oil	Brine	5000	87.8	0.1	1.2	---
5	WAG	Secondary	SP-I	Live Oil	Brine	3800	87.8	0.1	1.2	3-1
6	WAG	Secondary	SP-I	Live Oil	Brine	3800	87.8	0.1	1.2	1-1
7	WAG	Tertiary	Core	Dead Oil	Brine	3800	87.8	0.2	2.4	1-1
8	WAG	Tertiary	Core	Dead Oil	Brine	3800	87.8	0.2	2.4	2-1
9	WAG	Tertiary	Core	Dead Oil	Brine	3800	87.8	0.2	2.4	3-1

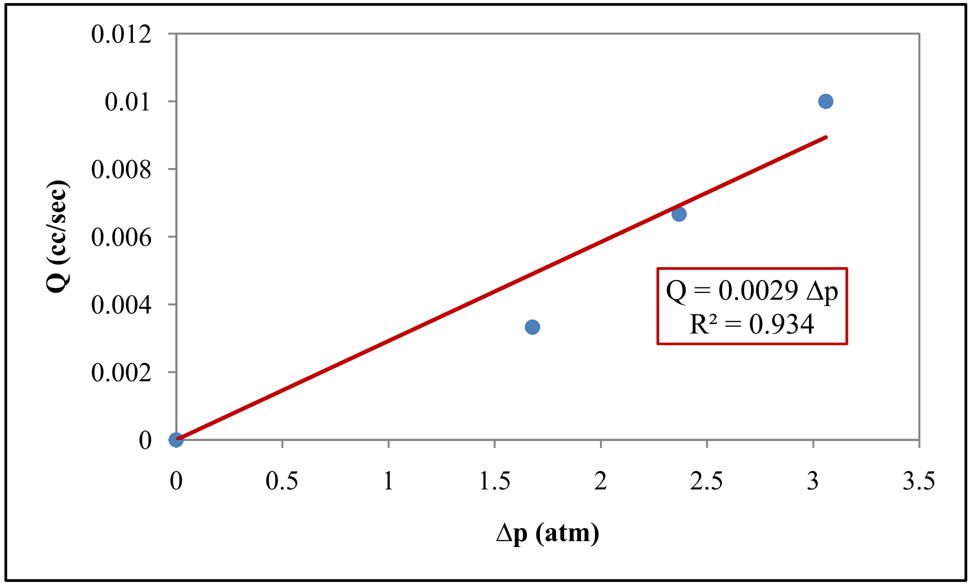
Continue …

Test	Porosity /%/	Irreducible Water Saturation /%/	Absolute Permeability /md/
1	33.57	29.44	45.23
2	33.89	15.15	48.35
3	33.89	8.81	53.02
4	32.50	26	48.35
5	32.67	16.25	56.25
6	31.63	19.17	45.23
7	18.10	27.27	379.10
8	18.10	23.07	379.10
9	18.10	25.32	379.10

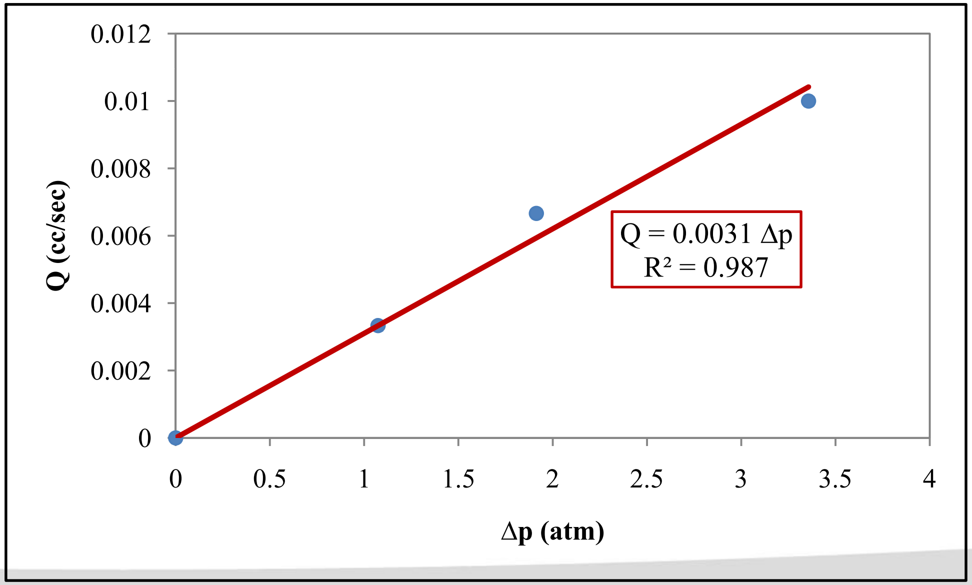
Brine Permeability Measurement



Brine Permeability In Test 1 & 2

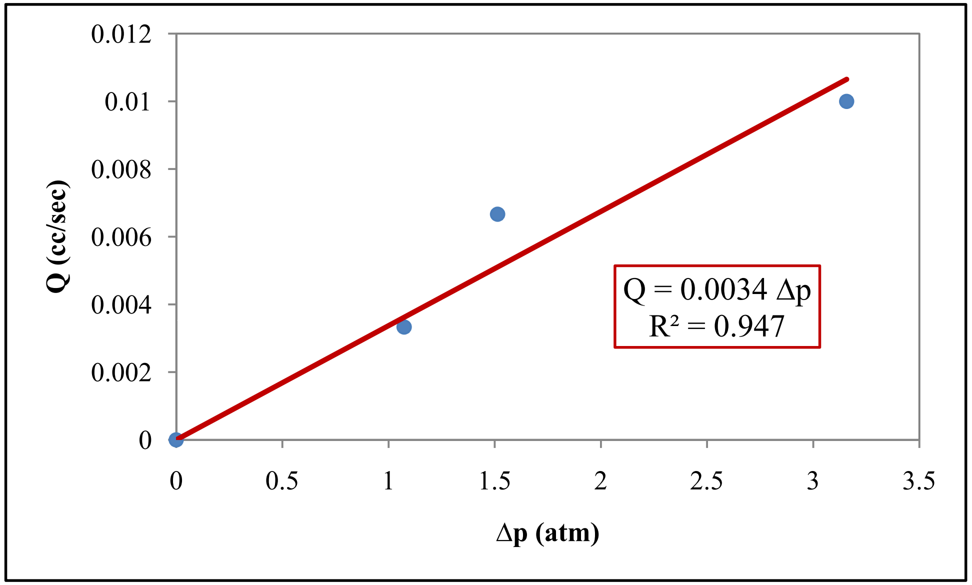


K = 45.23 md

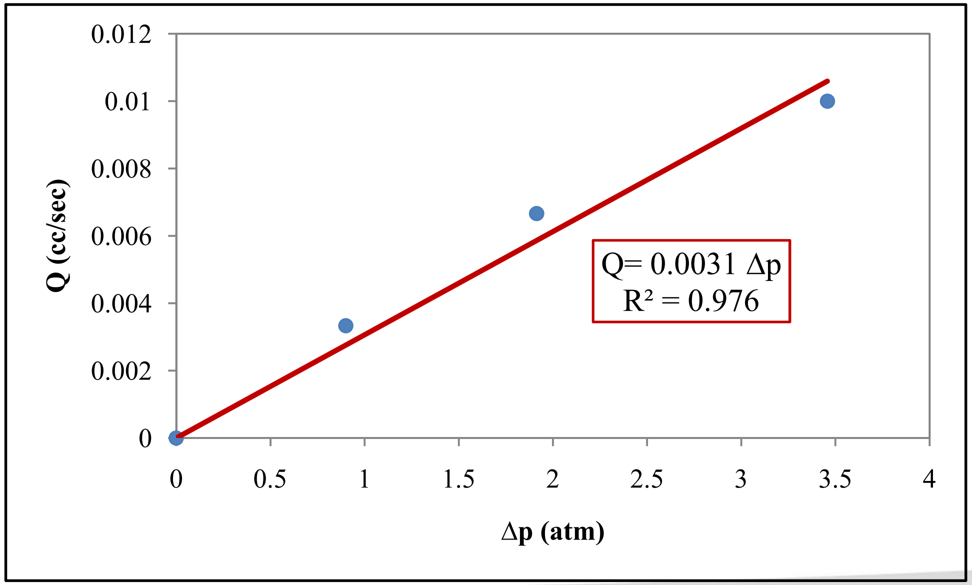


K = 48.35 md

Brine Permeability In Test 3 & 4

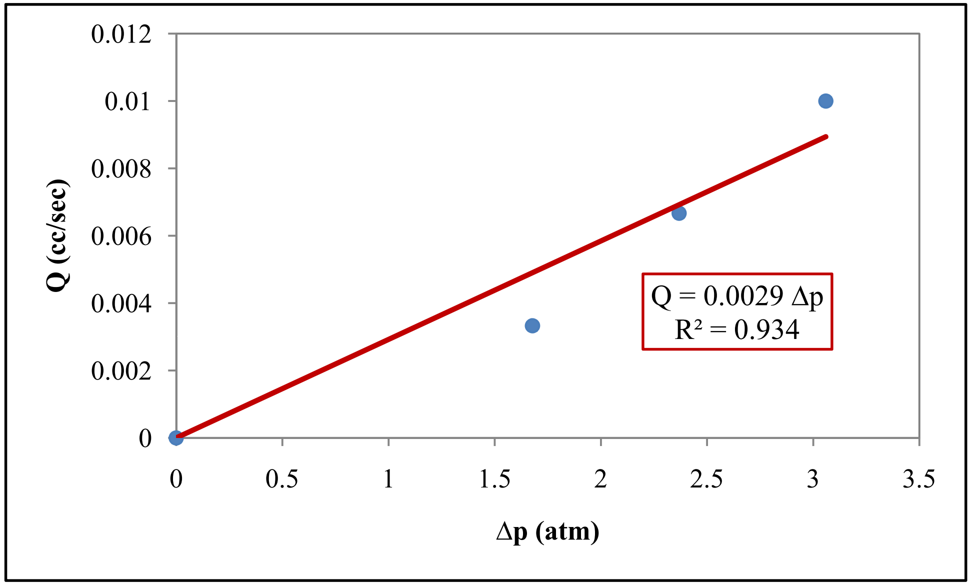


K = 53.02 md

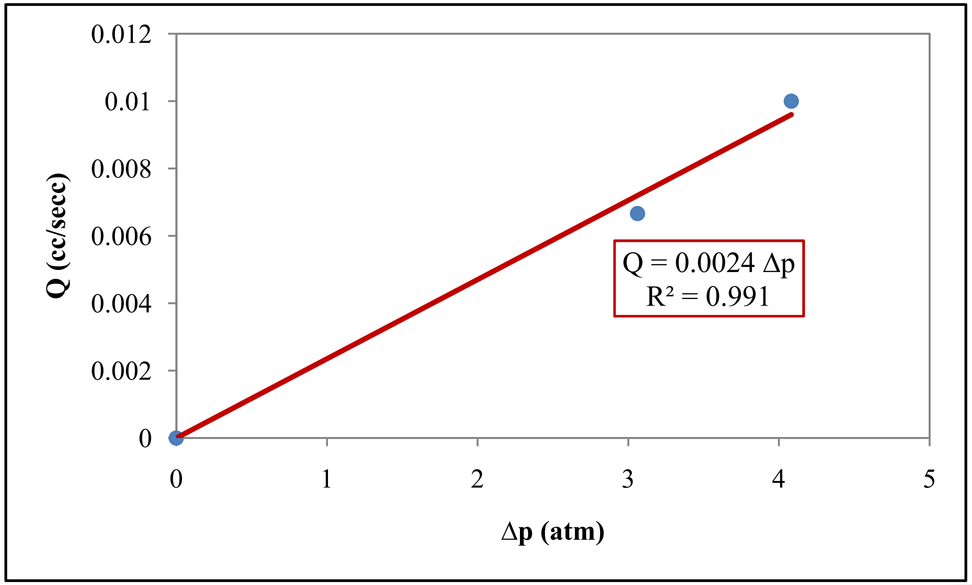


K = 48.35 md

Brine Permeability In Test 5 & 6

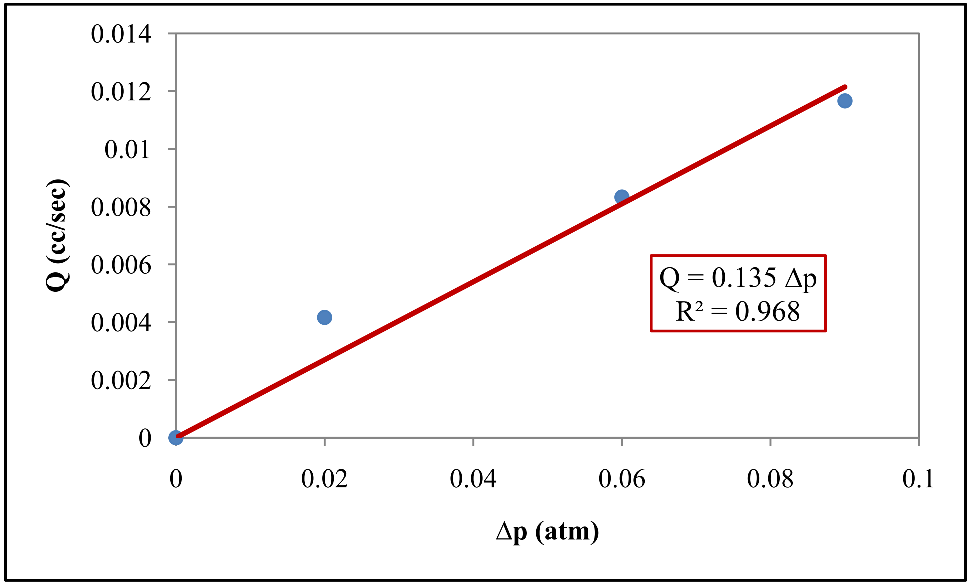


K = 53.02 md



K = 48.35 md

Brine Permeability in Core

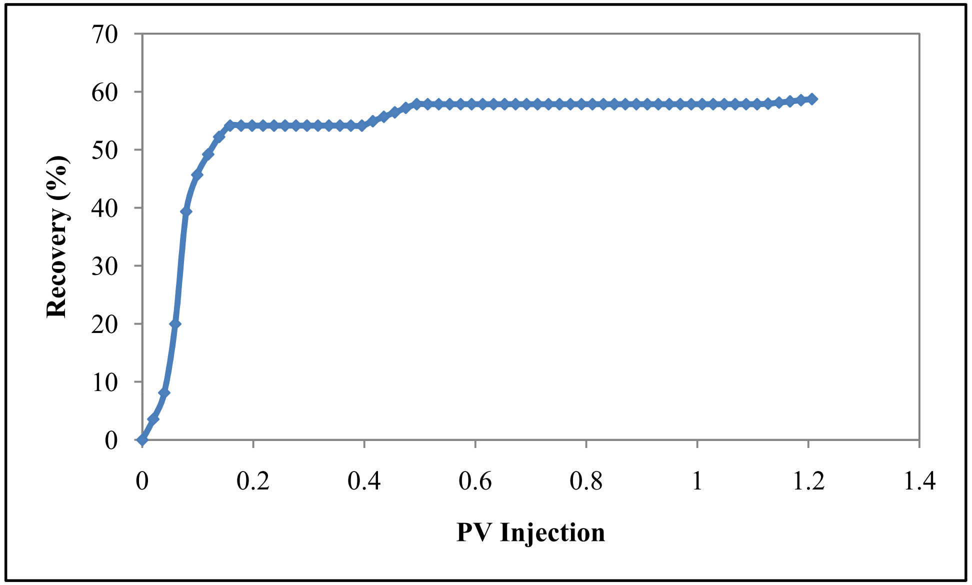


K = 379.10 md

Washing

Test 1

- P inj= 3800 psi
- Q inj= 0.1 cc/min
- Live Oil
- Sand Packed
- Secondary Stage
- Recovery= 58%

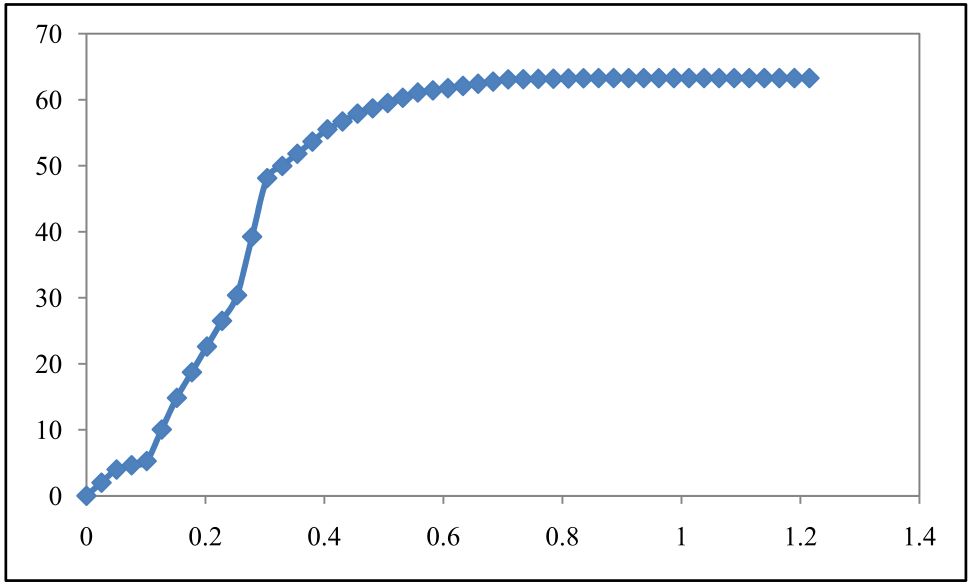


1.2 PV

CO_2 Injection

Test 2

- P inj= 4200 psi
- Q inj= 0.1 cc/min
- Live Oil
- Sand Packed
- Secondary Stage
- Recovery= 63%

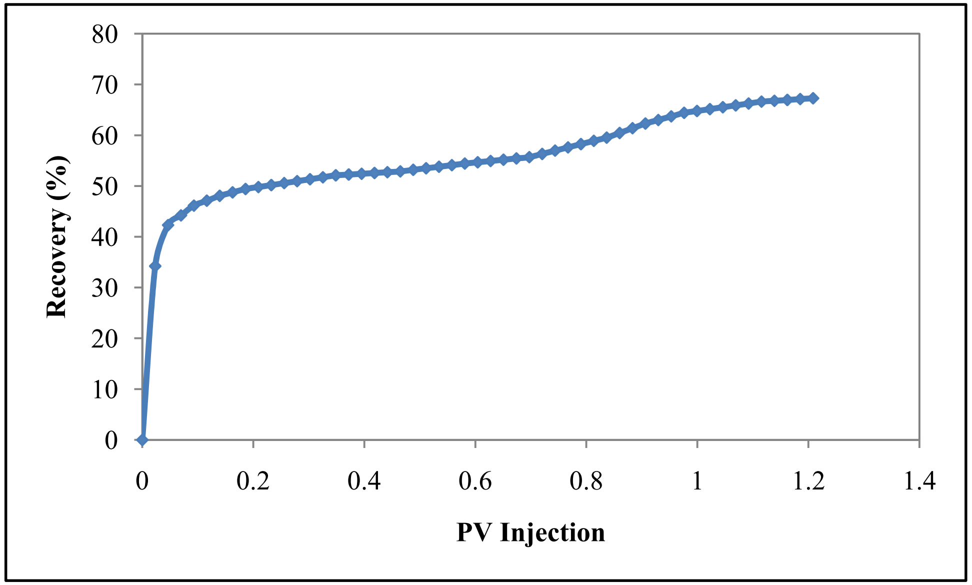


1.2 PV

CO_2 Injection

Test 3

- P inj= 4600 psi
- Q inj= 0.1 cc/min
- Live Oil
- Sand Packed
- Secondary Stage
- Recovery= 67%

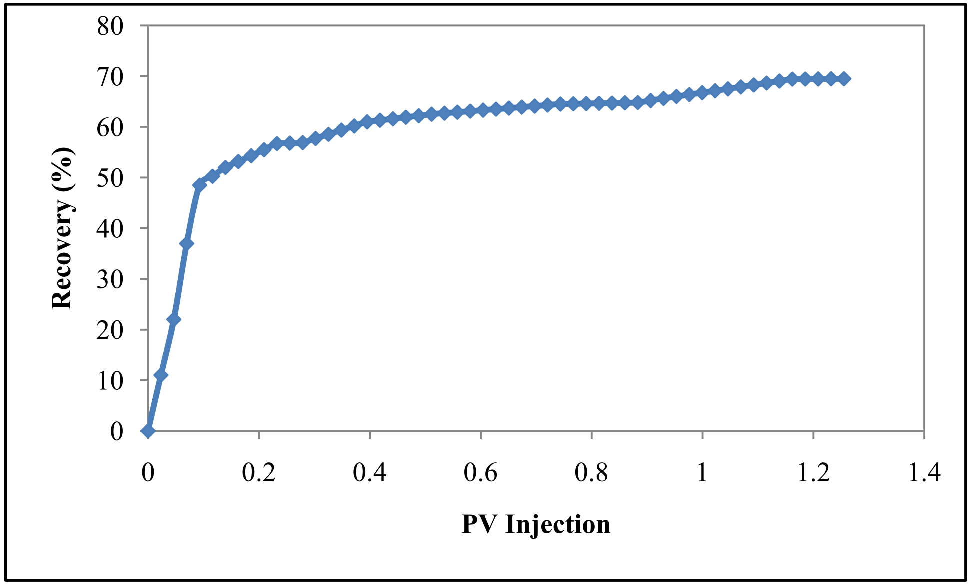


1.2 PV

CO_2 Injection

Test 4

- P inj= 5000 psi
- Q inj= 0.1 cc/min
- Live Oil
- Sand Packed
- Secondary Stage
- Recovery= 69%



1.2 PV

CO_2 Injection

Test 5

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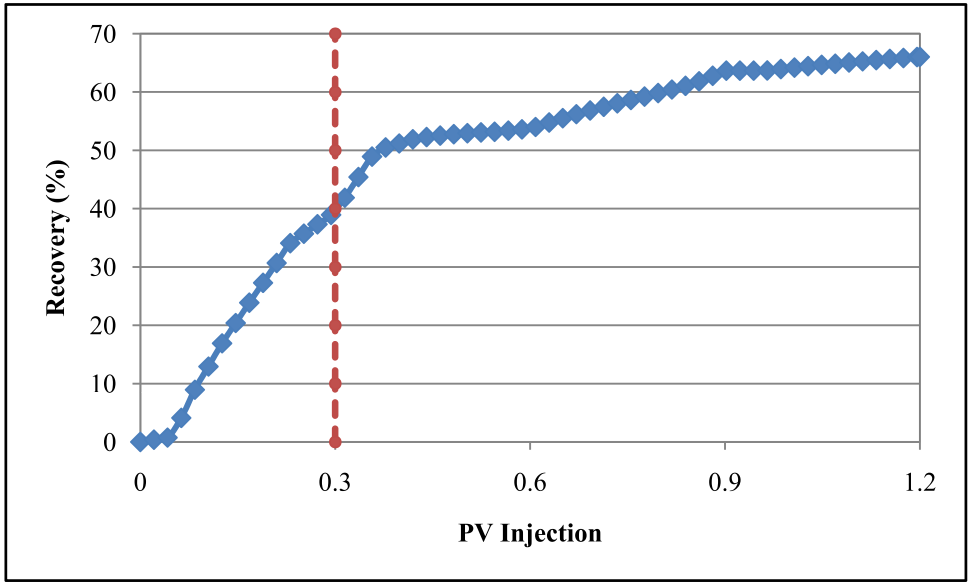
- P inj= 3800 psi
- Q inj= 0.1 cc/min
- Live Oil
- Sand Packed
- Secondary Stage
- Recovery= 66%

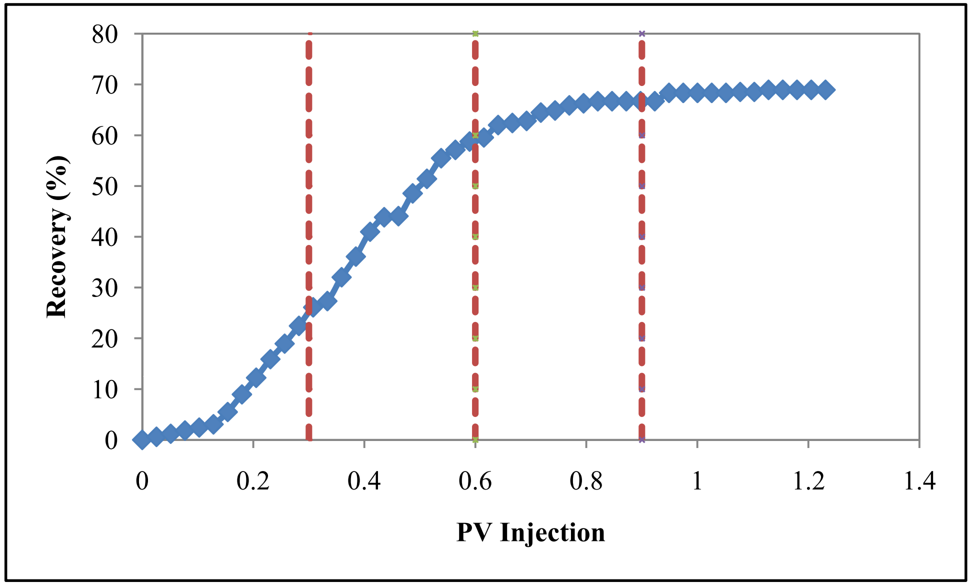


1.2 PV WAG

WAG Ratio = 1-3

Test 6

- P inj= 3800 psi
- Q inj= 0.1 cc/min
- Live Oil
- Sand Packed
- Secondary Stage
- Recovery= 69%



1.2 PV WAG

WAG Ratio = 1-1

Test 7

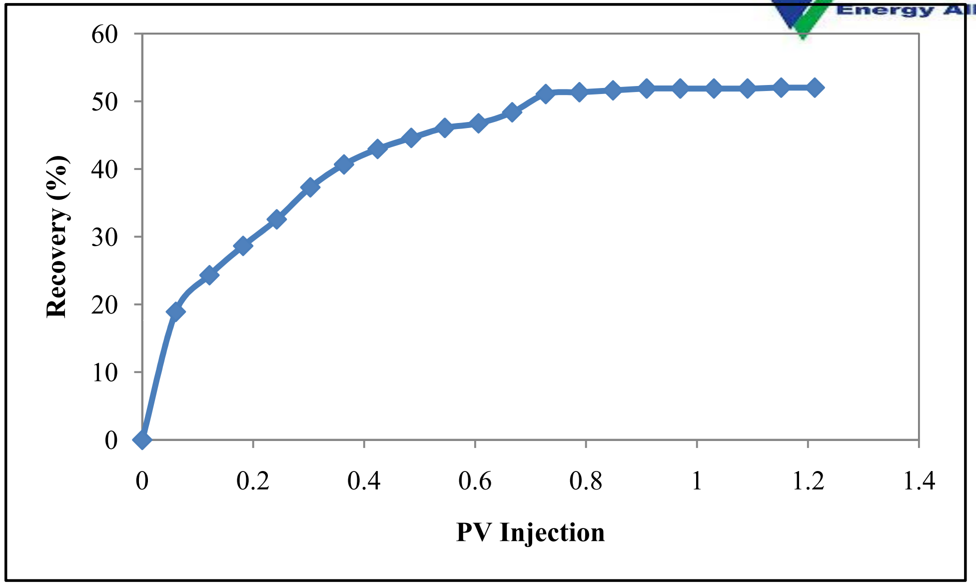
1.2 PV

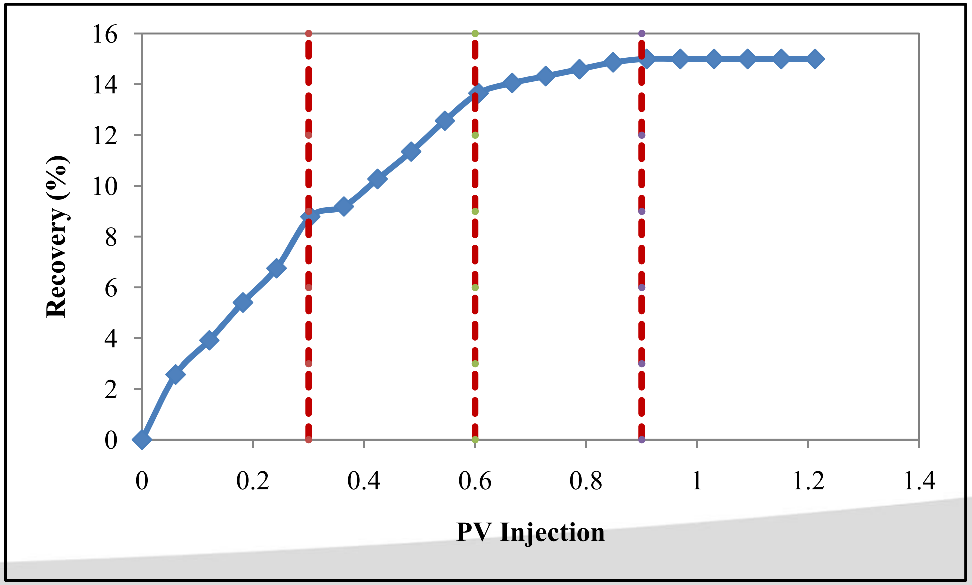
Water Flooding

- P inj= 3800 psi
- Q inj= 0.2 cc/min
- Dead Oil
- Core
- Tertiary Stage
- Recovery (Secondary, 52% +Tertiary, 15%) = 67%

1.2 PV WAG

WAG Ratio = 1-1





Test 8

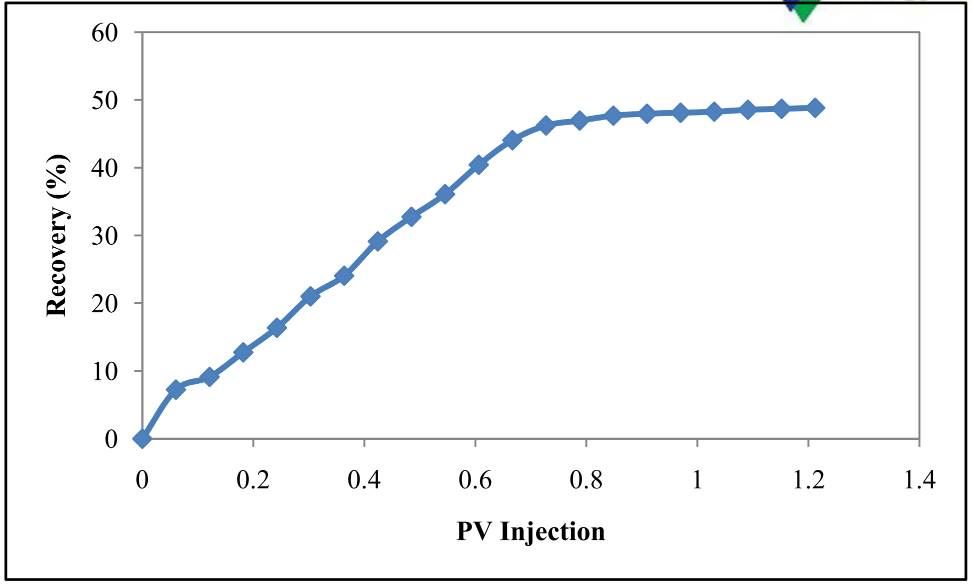
1.2 PV

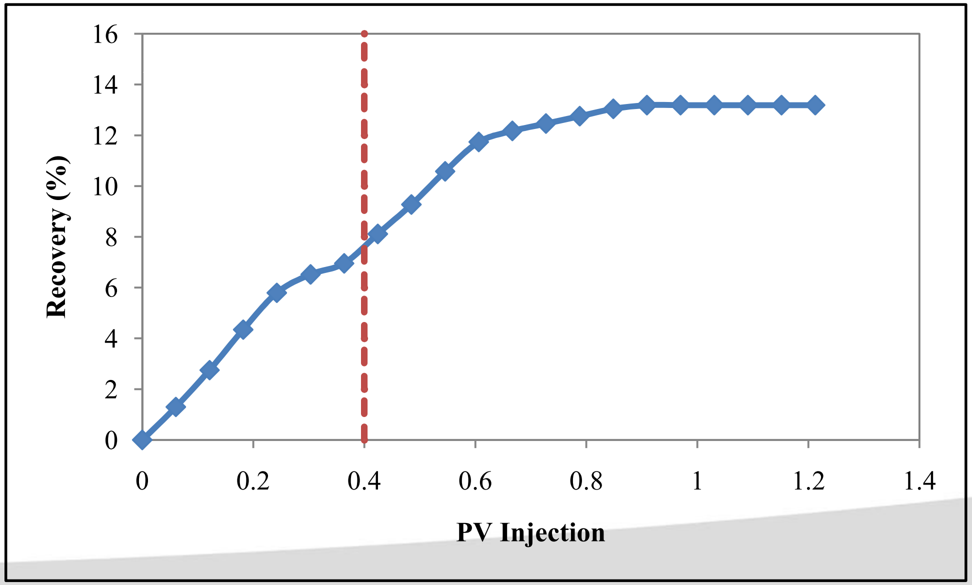
Water Flooding

- P inj= 3800 psi
- Q inj= 0.2 cc/min
- Dead Oil
- Core
- Tertiary Stage
- Recovery (Secondary, 48% +Tertiary, 13%) = 61%

1.2 PV WAG

WAG Ratio = 2-1





Test 9

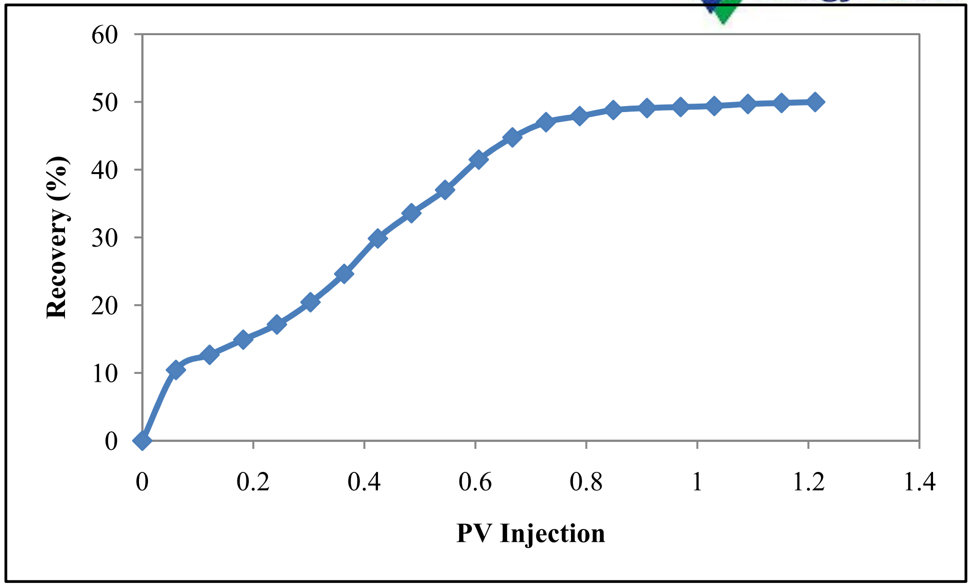
1.2 PV

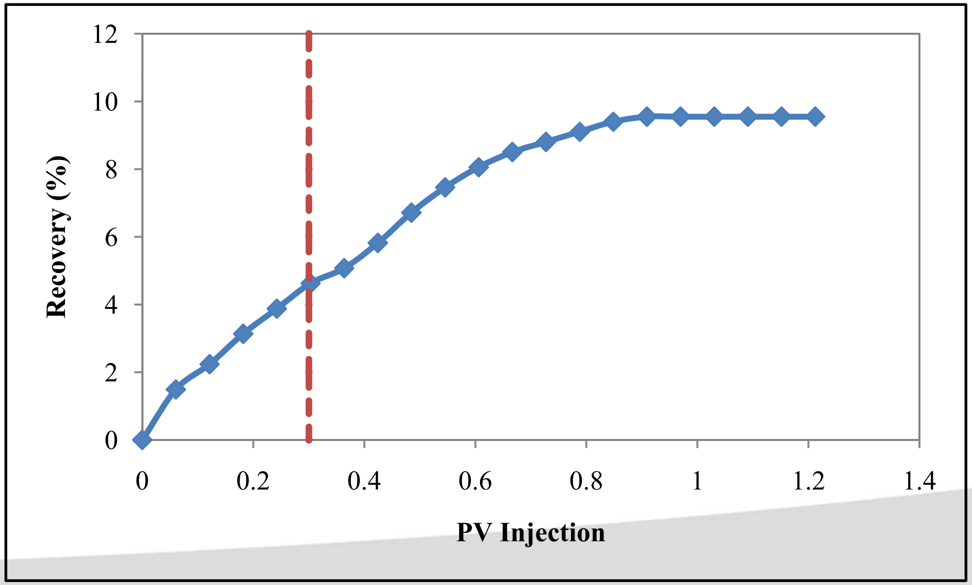
Water Flooding

- P inj= 3800 psi
- Q inj= 0.2 cc/min
- Dead Oil
- Core
- Tertiary Stage
- Recovery (Secondary, 50% +Tertiary, 9.5%) = 59.5%

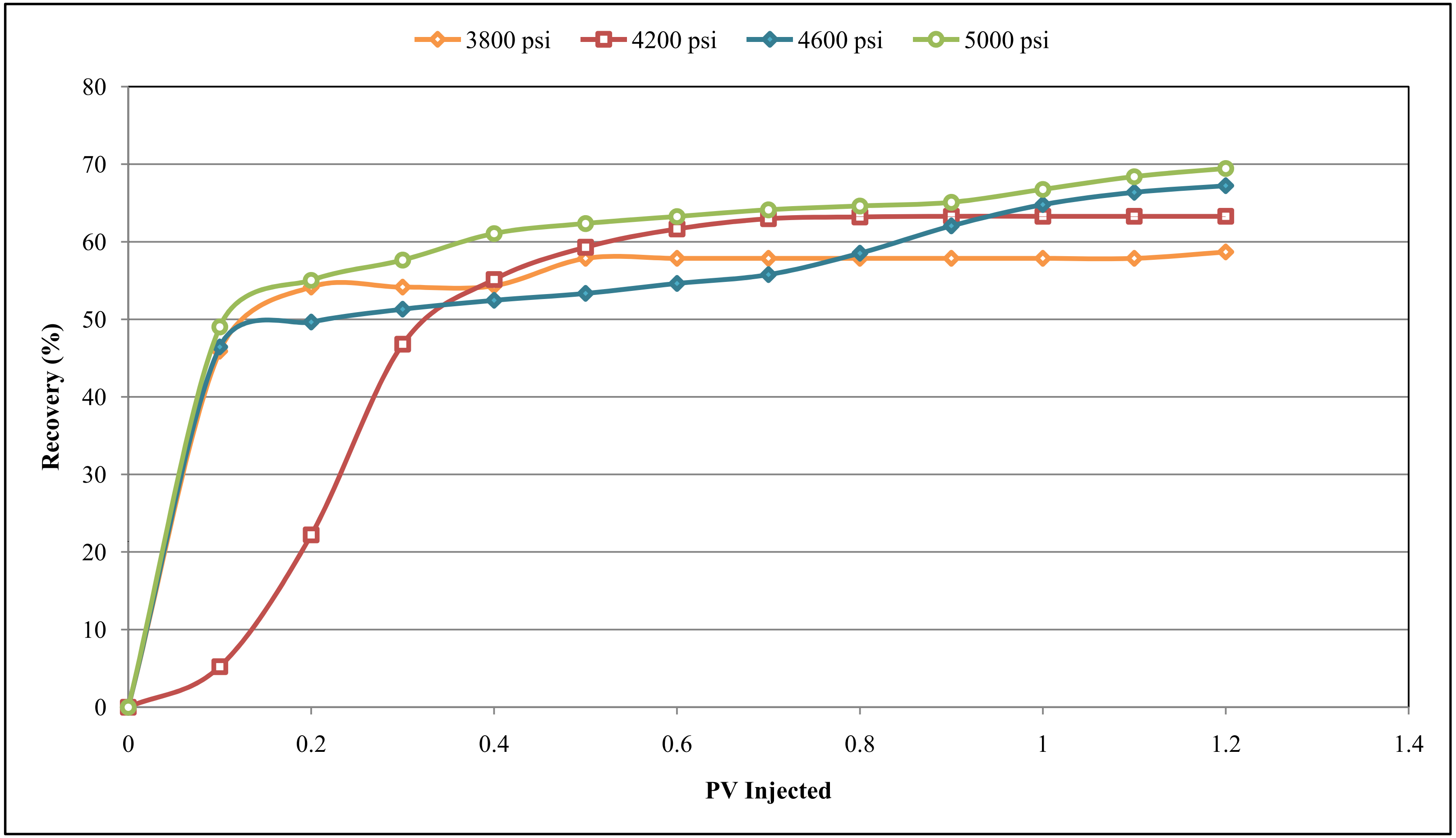
1.2 PV WAG

WAG Ratio = 3-1

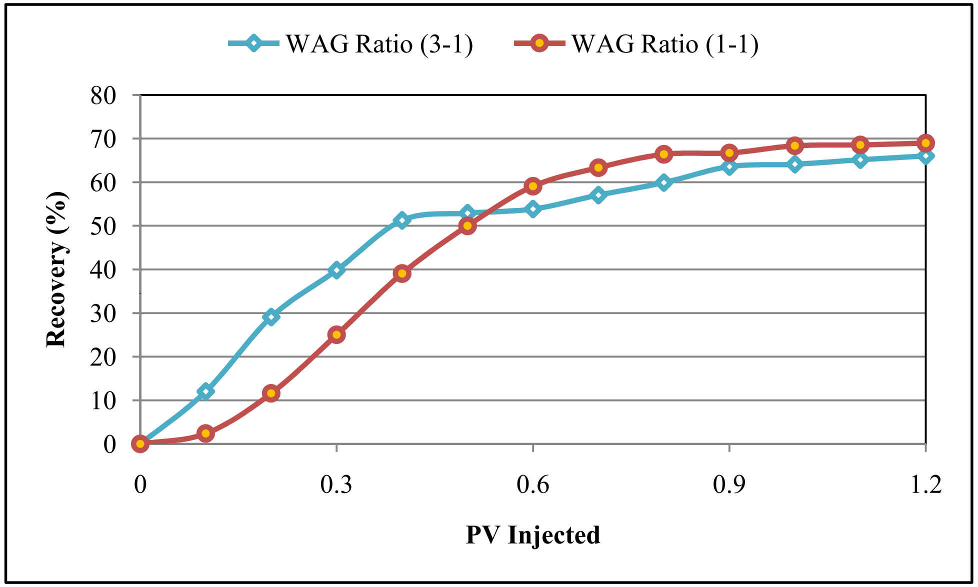




In Tests 1, 2, 3 & 4

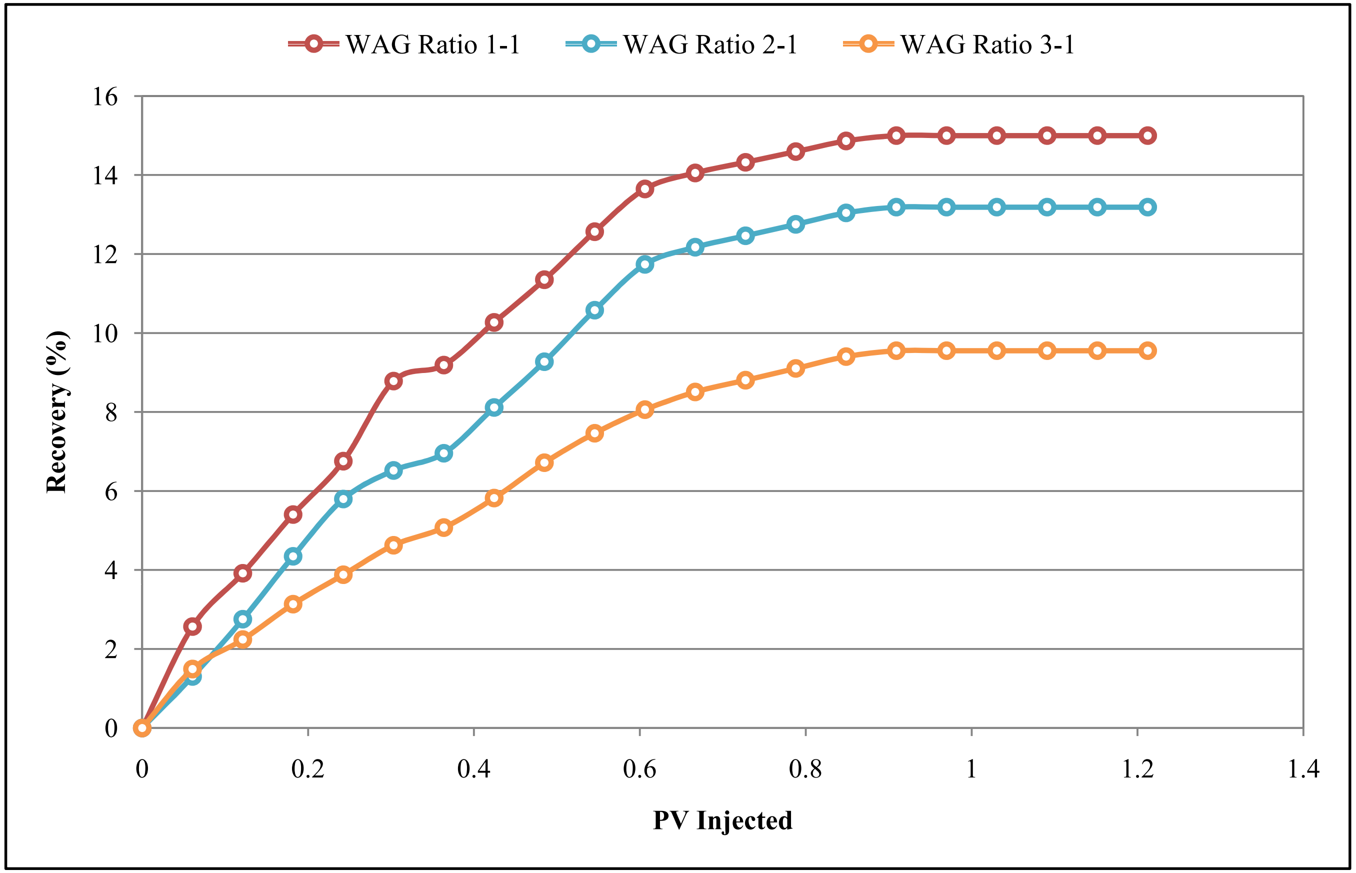


In Tests 5 & 6



WAG Ratio (3-1)
WAG Ratio (1-1)
Recovery (%)
0
10
20
30
40
50
60
70
80
0
0.3
0.6
0.9
1.2
PV Injected

In Tests 7, 8 & 9


WAG Ratio 1-1
WAG Ratio 2-1
WAG Ratio 3-1
Recovery (%)
PV Injected
0
2
4
6
8
10
12
14
16
0
0.2
0.4
0.6
0.8
1
1.2
1.4

Result

- ❑ In tests 1-4, By increasing the injection pressure in sand packed model (in gas injection) oil recovery will increase.

- ❑ In tests 5 & 6 (WAG Ratio in test 5 > WAG Ratio in test 6, oil recovery will decrease with increasing WAG Ratio in sand packed model.

- ❑ In tests 7-9, By decreasing the WAG Ratio in Core, oil recovery will increase.