Experimental Investigation on Factors Affecting Oil Recovery Efficiency during Solvent Flooding in Low Viscosity Oil Using Five-Spot Glass Micromodel

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Abstract

Lack of experimental study on the recovery of solvent flooding in low viscosity oil is obvious in previous works. This study concerns the experimental investigation on oil recovery efficiency during solvent/co-solvent flooding in low viscosity oil sample from an Iranian reservoir. Two micromodel patterns with triangular and hexagonal pore structures were designed and used in the experiments. A series of solvent flooding experiments were conducted on the two patterns that were initially saturated with crude oil sample. The oil recovery efficiency as a function injected pore volume was determined from analysis of continuously captured pictures. Condensate and n-hexane were employed as base solvents, and Methyl Ethyl Ketone (MEK) and Ethylene Glycol Mono Butyl Ether (EGMBE) used as co-solvents. The results revealed that not only does the solvent flooding increase the recovery in low viscosity oil but also this increase is evidently higher with respect to viscous oil. But, type of solvent or adding co-solvent to solvent does not noticeably increase the recovery of low viscosity oil. In addition, further experiments showed that presence of connate water or increasing injection rate reduces the recovery whereas increasing permeability improves the recovery. The results of this study are helpful to better understand the application of solvent flooding in low viscosity oil reservoirs.

Keywords: solvent flooding, low viscosity oil, co-solvent, micromodel, recovery.

1. Introduction

When a liquid hydrocarbon is injected into the reservoir, it fingers into the oil and spreads through the reservoir by diffusion or dispersion to decrease the oil viscosity by dilution [3]. The production is thus enhanced and the solvents are recovered and recycled. Solvent flooding is a commonly used technology for enhanced oil recovery in hydrocarbon reservoirs, which aims at developing miscibility, thereby mobilizing the residual oil and enhancing the mobility of the hydrocarbon phase. Light hydrocarbon solvents are usually applied for EOR miscible displacement, but it is always tried to improve their quality by adding some other chemicals. These chemicals are generally called as co-solvents and their behavior to improve the recovery efficiency is mainly influenced by the physical and chemical properties of the reservoir rocks and fluids [1].

Most of reported experiences in the literature applied the solvent flooding to viscous oils. But shortage of experiments on investigation of solvent behavior on low viscosity oil recovery is perceptible. Thereby, it's been tried to investigate the effects of solvent and co-solvent flooding on light oil recovery using glass micromodel. Moreover, a comparison between the effects of solvent flooding on viscous and low viscosity oil recovery is provided.

Glass micromodel is widely used for visualization of multiphase flow in porous media at the pore scale in common EOR methods. For example, visualization of immiscible and miscible displacements [5], hydrocarbon solvent flooding [2], water and gas injection processes alternatively or alone [7] and other enhanced oil recovery schemes.

In this work Quarter-Five-Spot micromodel was implemented to survey the role of two solvents, n-Hexane and Condensate, two co-solvents, MEK and EGMBE, as well as injection rate, pore structure and presence of connate water on recovery efficiency of low viscosity oil with the aid of captured pictures of micromodel during flooding processes.

2. Experimental Set up

In this work two glass micromodel patterns were designed by special software on the basis of pore geometry of reservoir rock and were constructed during a specific process.

Pattern A: structure of pores in this pattern was selected to be triangle according to statistical evidences on morphology of limestone rock sample from the reservoir. The properties of this pattern are given in table (1). The scheme of this pattern is demonstrated in figure (1).

Table (1) physical and hydraulic properties of Pattern A and B

Pattern	A	B
Length(cm)	6.01	6.02
Width(cm)	5.98	5.98
Average Depth(μ)	55	50
Porosity (%)	45	35
Absolute Permeability(D)	2.05	1.8
Pore-Throat ratio	6	4

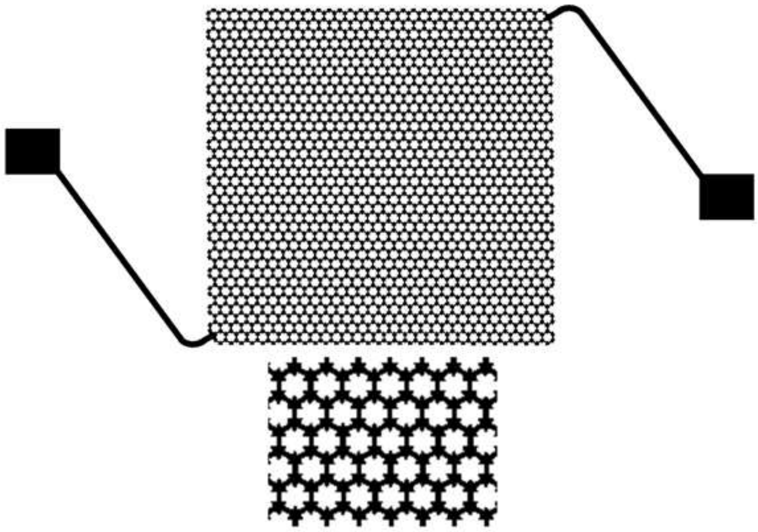

Fig. (1) Scheme of pattern (A) (triangular pore structure) and a selected magnified section

Pattern B: This pattern is uniform in structure and has one inlet and one outlet as same as pattern A. The pores in this pattern were selected to have hexagonal geometry figure (2). Properties of this pattern are shown in table (1).

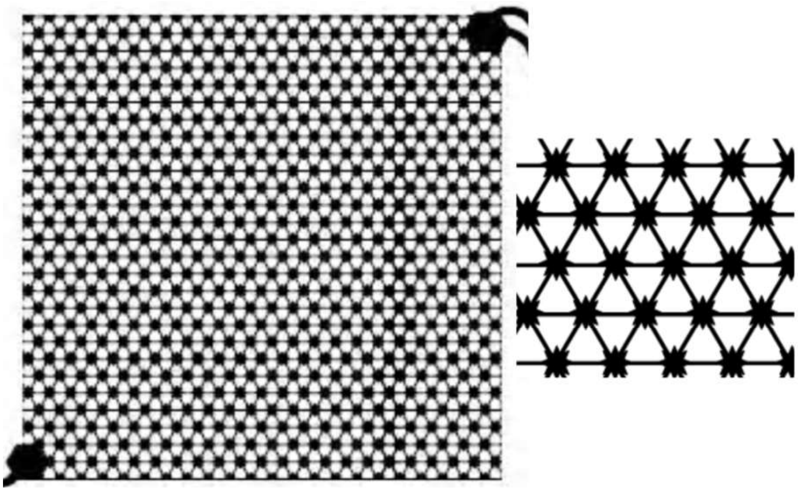

Fig. (2) Scheme of a triple hexagonal pattern B

Three types of oil samples; A, B and C, were used to observe the effects of solvent on their recovery. Properties of these three samples are given in table (2). According to properties shown in this table, sample A is low viscous, B has medium viscosity and C is viscous.

Table (2) Oils properties

Oil Types	°API	Dead Oil Viscosity(cp)
A	43.6	4.24
B	20.4	150
C	8.46	1120

Two types of hydrocarbon were used as solvents. One was condensate, supplied from Iranian oil flied, and the other was n-Hexane. Properties of these two hydrocarbons are illustrated in table (3).

Table (3) Solvent physical properties

Hydrocarbon	**Formula**	**Molecular Weight(g/mol)**	**Specific gravity**
Condensate	C_2-C_6	30-86	0.8575
n-Hexane	C_6H_{14}	86.18	0.659-0.662

Two types of co-solvent, Methyl Ethyl Ketone (MEK) and Ethylene Glycol Mono Butyl Ether (EGMBE), were used with same concentrations in order to investigate effects of co-solvent on recovery. Properties of these two types of co-solvent were shown in table (4).

Table (4) Co-solvent physical properties

Co-solvent	Formula	Molecular Weight (g/mol)	Specific gravity
EMGBE	$C_6H_{14}O_2$	118.19	0.900 - 0.901
MEK	C_4H_8O	72.11	0.804 – 0.805

According to reservoir water analysis, the composition of connate water which was used in this study is given in table (5).

Table (5) compositions of Brine (136000PPM)

Formula	Molecular Weight(g/mol)	Concentration(g/lit)
Nacl	58.44	102
$Mgcl_2.6H_2O$	203.3	1
$Cacl_2.2H_2O$	147.03	3
Na_2so_4	142.04	30

3. Results and Discussions

This part of our study focuses on investigating the effects of two types of solvents, two types of co-solvents, pore structure, injection rate and connate water on low viscosity oil recovery. Several tests have been performed in order to reach the mentioned goals.

The glass micromodel was washed with sequential injection of toluene, distilled water and alcohol before each experiment. Prior to beginning of the test, special chemical processes were applied to make the glass pattern an oil wet medium. The glass micromodel was saturated with crude oil sample. Then the solvents were injected to micromodel through inlet port in ambient temperature and 47 psi as injection pressure.

3.1. Effect of Injection Rate

Three tests were carried out in order to investigate the effect of injection rate on recovery. Pattern A was chosen for these experiments and flooded by condensate in three rates;0.0006cc/min,0.0008cc/min and 0.001cc/min. Details and specification of all three tests are given in table (6).

Table (6) Different Injection Rate

Test No.	T(°C)	Injection Rate(cc/min)	BT(PV)	BT(min)	RF at BT	RF at 1 PV
1	27	0.0006	0.29	35	70.34	88.7
2	26	0.0008	0.21	25	57.6	85.7
3	26	0.001	0.2	24	59.1	81.57

Due to fingering phenomena, increasing injection rate reduces the recovery figure (3). Among the three flow rates, 0.0008cc/min was chosen which is equivalent to approximate velocity of 1.3 ft/day in reservoir condition because it is optimum in terms of time and recovery.

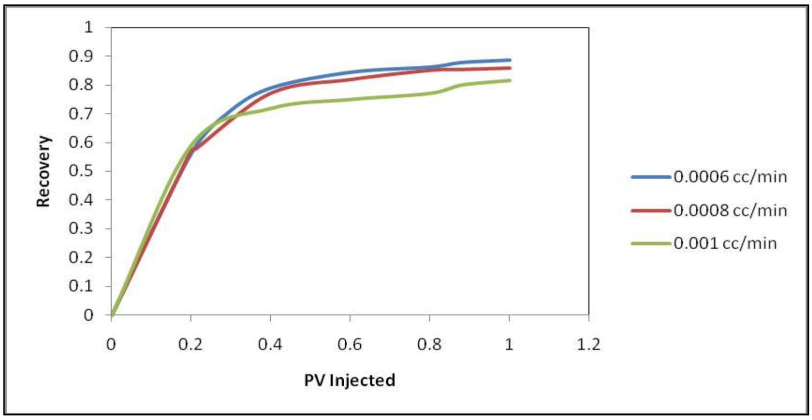

Fig. (3) Oil recovery in different rate injection

3.2. Effects of Solvent Type

Pattern B was selected for this set of experiments. The pattern was oil wet medium. At first step of the experiment, the pattern was saturated with crude oil sample. Then it was flooded with two types of solvents separately. Tests four and five were carried out in order to show the effects of solvent types on oil recovery. The injection rate and injection pressure for both tests were 0.0008cc/min and 47psi, respectively. Table (7) shows results of experiments.

Table (7) Different types of solvent flooding

Test No.	T(°C)	Solvent Type	BT(PV)	BT(min)	RF at BT	RF at 1 PV
4	27	n-Hexane	0.27	25	51.49	67.04
5	26	Condensate	0.72	68	62.64	69.95

The effect of solvent type on recovery is illustrated in figure (4). In spite of dissimilar behavior of two solvents during flooding, there is not dramatic difference between ultimate recoveries. Condensate showed longer breakthrough time than Hexane and the recovery rose moderately till it reached the breakthrough. But when flooded with Hexane, the recovery went up rapidly and reached breakthrough very earlier than that of condensate. Therefore, due to longer breakthrough time and higher recovery, Condensate is a preferred solvent in this study. Figures (9 & 10) illustrate six stages of Condensate and Hexane flooding in pattern B respectively.

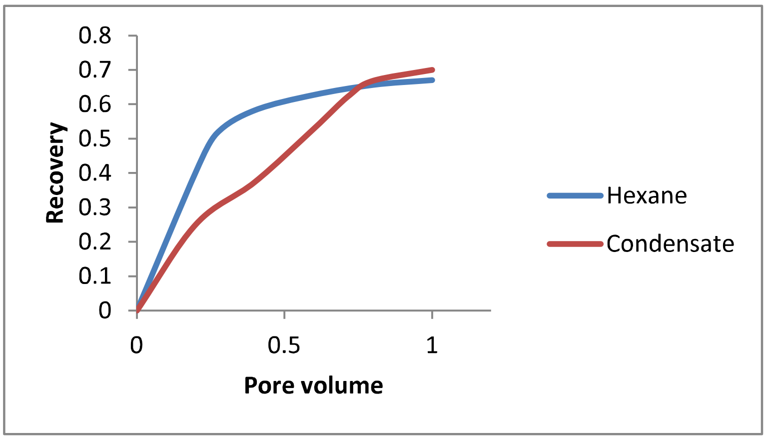

Fig. (4) Effects of Hexane and Condensate on recovery

3.3. Effects of Co-Solvent

In this part of experiment, two tests were carried out to observe the effects of two co-solvents, EMGBE and MEK, when added to condensate on recovery. Pattern B was saturated with crude oil sample and then flooded with condensate in two separate tests: test six with EMGBE and test seven with MEK. The two tests were performed under the same conditions and the same injection rate (0.0008cc/min) with the same co-solvent concentration of 20 v/v%. Details and results of the two tests are given in table (8).

Table (8) Different types of co-solvent

Test No.	T(°C)	Co-Solvent Type	BT(PV)	BT(min)	RF at BT	RF at 1 PV
6	26	EMGBE	0.86	81	68.91	71.4
7	25	MEK	0.81	76	68.53	69.94

The ultimate recovery was nearly the same in the two tests. Figure (5) shows this fact. According to this figure adding co-solvent to condensate has negligible effect on performance of solvent flooding and thus recovery. Thus, using condensate without co-solvent is technically and economically preferred.

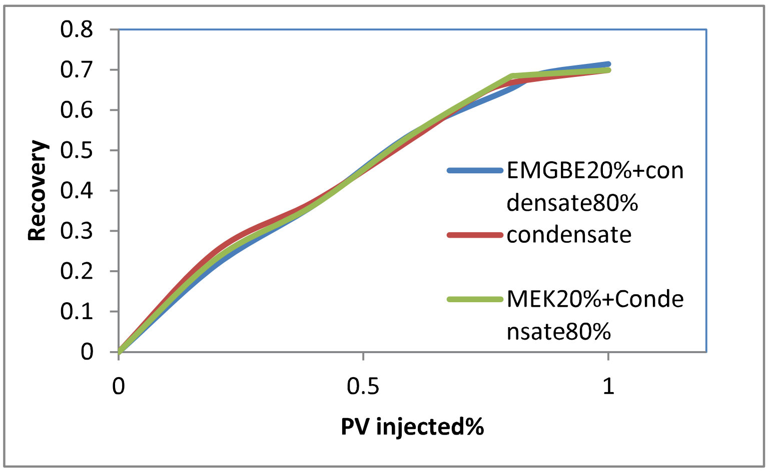

Fig. (5) Changing Co-solvent in solvent flooding

3.4. Effect of Pore Structure

The aim of this part of study is to compare the effect of pore structure in condensate flooding. As previously described, test five and test two were run on both patterns B and A with condensate as solvent. Same injection rate (0.0008cc/min) was adjusted for two tests. Table (9) shows details of these two experiments.

Table (9) Effect of different Patterns

Test No.	T(°C)	Pattern	BT(PV)	BT(min)	RF at BT	RF at 1 PV
5	26	B	0.72	68	62.64	69.95
2	25	A	0.21	25	57.61	85.7

The main parameters influencing solvent flooding performance are diffusion and dispersion. Since solvent can easily diffuse and disperse in oil when medium is high permeable, increasing permeability causes growth in ultimate recovery. Figure (6) indicates that using pattern A results in higher recovery since this pattern has higher permeability (according to table (1)).

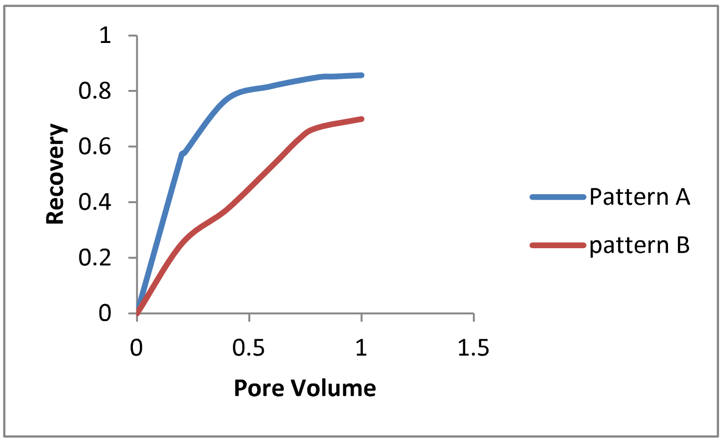

Fig. (6) Effect of Pore structure in solvent flooding

3.5. Effect of Connate water

Investigation of connate water effect in solvent flooding on recovery is the target of this section. To observe this effect, Test 8 was conducted using pattern B. At first step, the pattern was saturated with brine 136000PPM, and then flooded with crude oil sample to leave connate water in pores. At second step the pattern was flooded with condensate. Test 8 was compared with Test 5(mentioned earlier). Table (10) shows details of the tests.

Table (10) Effect of connate water

Test No.	T(°C)	Connate water(Sw)%	BT(PV)	BT(min)	RF at BT	RF at 1 PV
5	26	0	0.72	68	62.64	69.95
8	26	8	0.4	37	37.1	63.01

Presence of connate water reduces breakthrough time, by occupying some pores and thus shortening the solvent path during flooding, and declines the ultimate recovery. Figure (7) demonstrates the effect of presence of connate water on recovery.

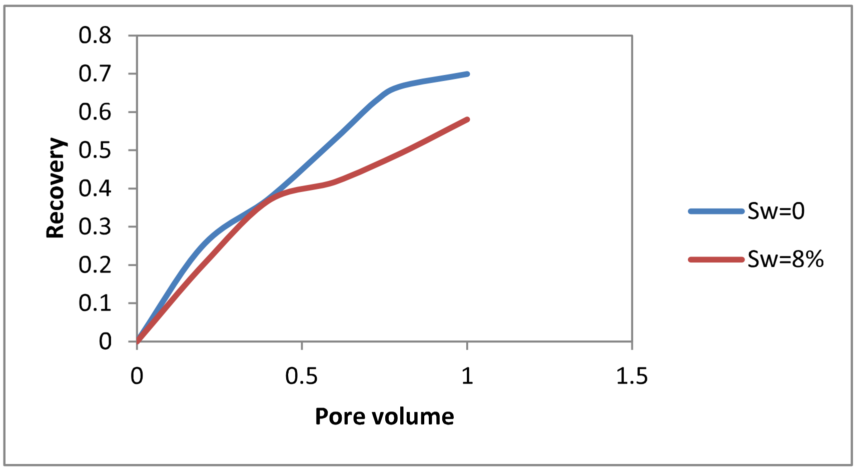

Fig. (7) Effect of connate water in solvent flooding

3.6. Effect of Oil Type

Last part of this study concerns the effect of solvent flooding on recovery of different oil types. To do so, three tests were performed in order to compare recovery of low viscosity oil and viscous oil. Test 9 and 10 were carried out on two heavy oil types, B and C, in pattern A using condensate as solvent and were compared with outcomes of condensate injection in low viscosity oil (Test 2). Note that all conditions are similar in all three experiments. Details are given in table (11).

Table (11) Solvent injection in three different oil types

Test No.	T(°C)	Oil type	BT(PV)	BT(min)	RF at BT	RF at 1 PV
2	26	A	0.21	25	57.6	85.7
9	26	B	0.23	28	16.5	36
10	27	C	0.25	30	15.12	24.64

Figure (8) shows that there is great difference between oil recoveries in the case of low viscosity oil than viscous oil. This is due to the fact that solvent diffuses more easily in low viscosity oil than viscous oil causes higher recovery of low viscosity oil.

As illustrated in figure (8) there is not considerable difference in recoveries between two heavy oil samples, B with 150 cp and C with 1120 cp, whereas recovery rises dramatically when the oil becomes light, sample A with 4.24cp.

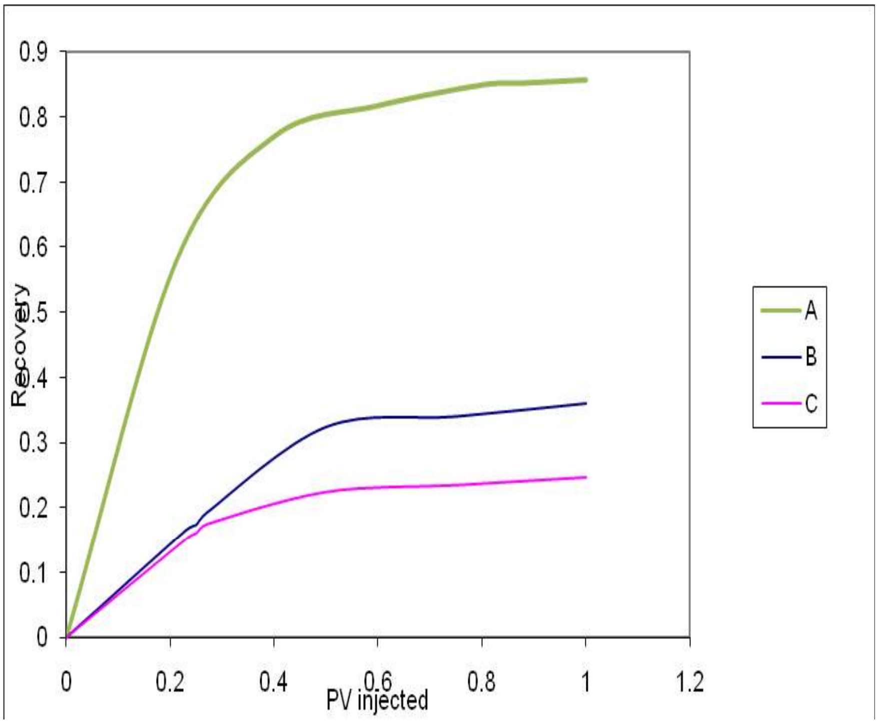

Fig. (8) Recoveries of solvent injection in different oil types

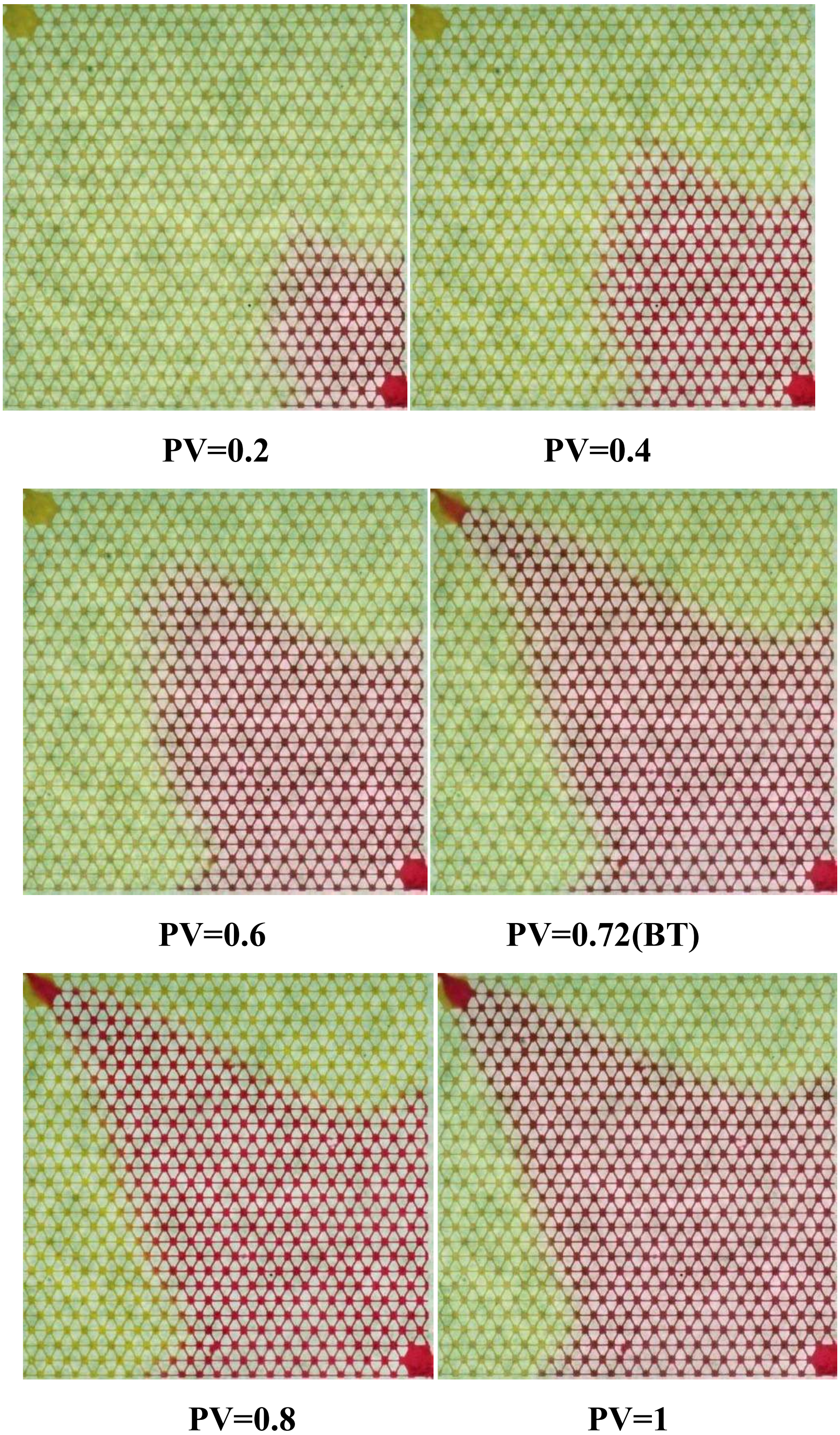

Fig. (9-6) Stages of condensate flooding in pattern B

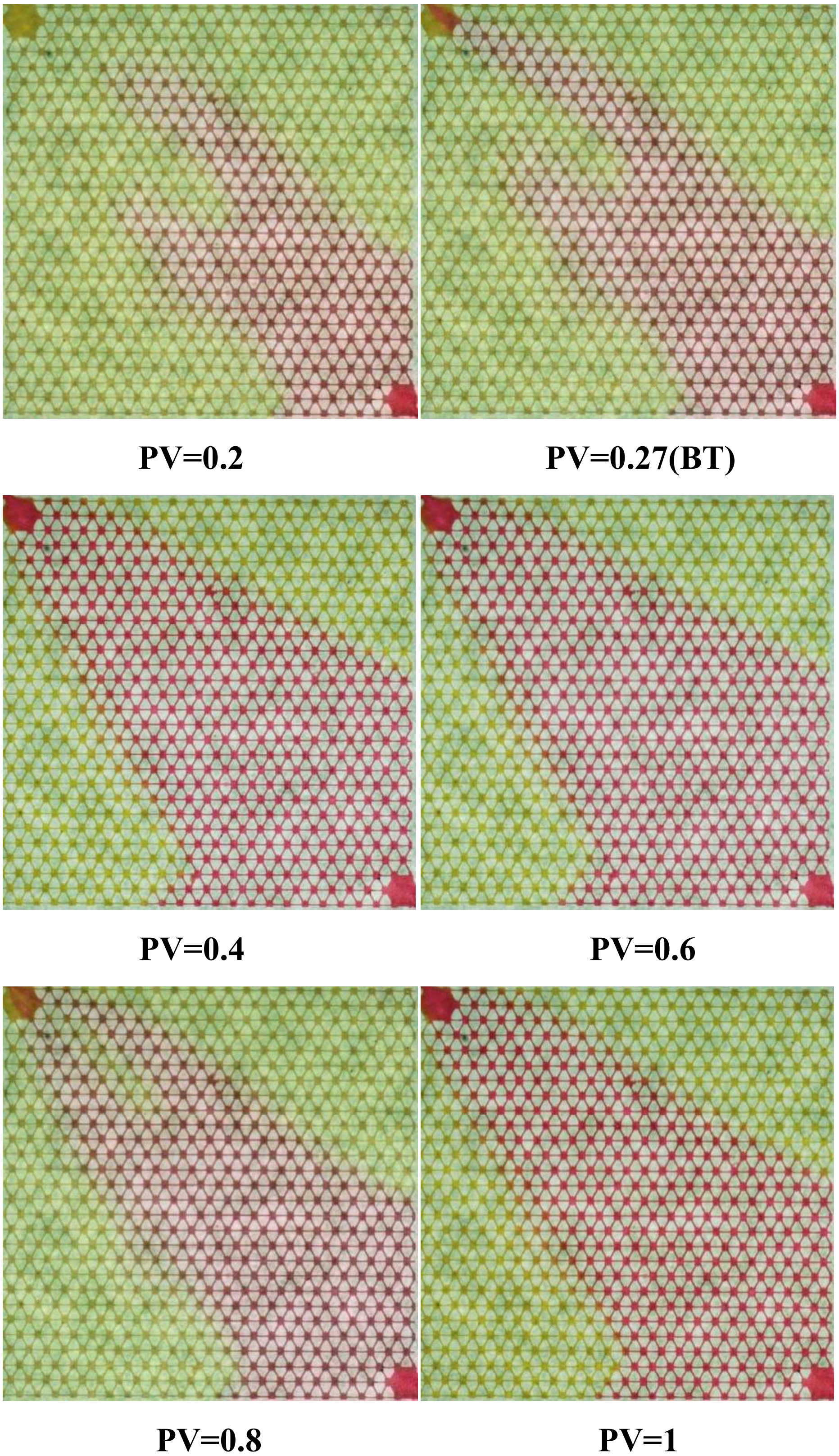

Fig. (10 -6) Stages of Hexane flooding in pattern B

4. Conclusions

Based on the results of this work the following can be concluded:

- Increasing injection rate reduces the recovery.
- Due to longer breakthrough time and higher recovery, Condensate is a preferred solvent respect to n-Hexane for low viscosity oil.
- Adding co-solvent to condensate has negligible effect on performance of solvent flooding and thus recovery.
- Increasing permeability causes growth in ultimate recovery in solvent flooding.
- Presence of connate water reduces breakthrough time and declines the ultimate recovery
- There is great difference between oil recoveries in the case of low viscosity oil than viscous oil.

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Nomenclatures

Sw	Connate Water saturation
API	Specific Gravity(°API)
RF	Recovery Factor
IFT	Interfacial Tension
BT	Break Through
PV	Pore volume
BP	Bubble point Pressure
MEK	Methyl Ethyl Ketone
EGMBE	Ethylene Glycol Mono Butyl Ether