Investigation of Factors Influencing Dispersion of Liquid Hydrocarbons in Porous Media

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ABSTRACT

An experimental work has been done to study the major factors that affect the axial dispersion of some hydrocarbons during liquid-liquid miscible displacement. Kerosene and gas oil are used as displacing phase while seven liquid hydrocarbons of high purity represent the displaced phase, three of the liquids are aromatics and the rest are of paraffinic base. In conducting the experiments, two packed beds of different porosity and permeability are used as porous media.
The results showed that the displacement process is not a piston flow, breakthrough of displacing fluids are shown before one pore volume has been injected. The processes are stable with no evidence of viscous fingering.

Dispersion model as adapted by Brigham et.al (1961) is used to determine the axial dispersion coefficient of displacing fluid. The results show an increasing in dispersion coefficient as the interstitial velocity and viscosity ratio increases.

Key words: dispersion, viscosity ratio, interstitial velocity, axial

دراسة العوامل المؤثرة على تشتت الهيدروكاربونات السائلة في الوسط المسامي

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الخلاصة

أجريت دراسة مختبرية لتحديد العوامل المؤثرة على تشتت بعض السوائل الهيدروكاربونية اثناء الازاحة الامتزاجية في الوسط المسامية.استخدم النفط الابيض وزيت الغاز كاطوار مزيحة وسبعة مركبات عالية النقاوة كاطوار مزاحة. اربع من هذه المركبات ذات اساس برافيني والثلاث المتبقية ذات اساس ارروماتي.أجريت التجارب في وسطين مساميين ذوا قيم مختلفة للمسامية والنفاذية.
اظهرت النتائج ان عملية الازاحة لاتحصل بشكل مكبسي بل يظهر اختراق للطور المزيح قبل حقن حجم مسامي واحد من ذلك الطور. كذلك بينت النتائج ان الازاحة كانت مستقرة ولايوجد دليل لحصول ظاهرة التصبع اللزج .تم حساب معامل التشتت ولوحظ زيادة في قيمة هذا المعامل بزيادة السرعة الموقعية للطور المزيح ونسبة اللزوجة بين الطور المزاح والطور المزيح.

الكلمات الرئيسية: التشتت. نسبة اللزوجة. السرعة الموقعية. المحوري.

1. INTRODUCTION

During miscible displacement a transition zone develops gradually across the sharp interface. The evolution of such zone is controlled by dispersion. Dispersion is described in terms of two components at right angel: 1-Axial dispersion. 2- Radial dispersion.
Dispersion occurs in ground water flow, chemical engineering processes and miscible displacement in enhanced oil recovery.
Von Rosenberg and **Baker** ,**1956**; **Handy**,**1959**; **Brigham et al**.,**1961**;**Perkins** and **Johnston**,**1963**; **Shengkai** and **Wojtanowicz**,**2008**; **Mostaghimi et al**.,**2010** and **Raman et al.,2011** studied dispersion mechanisms in porous media. The previous studies mostly depended on convection-dispersion equation:

$$\frac{\partial^2 c}{\partial x^2} - v\frac{\partial c}{\partial x} = \frac{\partial c}{\partial t} \tag{1}$$

Brigham, 1961 solved Eq.(1) to calculate the concentration of displacing fluid as given by Eq.(2)

$$c = \frac{1}{2} erfc\left[\frac{L.U}{2\sqrt{KTV_p}}\right] \tag{2}$$

Brigham 1961 showed that a graph of concentration of displacing fluid versus a volume modifying function U, on a probability paper yields a straight line and the dispersion coefficient K, can be determined as follows:

$$k = \frac{1}{v_p T}\left[l\,\frac{U_{90} - U_{10}}{3.625}\right]^2 \tag{3}$$

$$U = \frac{V_{p-}\,V_i}{\sqrt{V_i}} \tag{4}$$

2. EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The equipment used to conduct the experiments is consisting of three sections. a- saturation-displacing section, this section consists of two positive displacement pumps (Ruska 2248). b- test section: two stainless-steel coils of 0.625 cm(ID) packed with glass beads of size range of 80-100 mesh as porous medium. Table 1 indicates the properties of test section. c- Concentration measurement instrument. **Fig.1** is a schematic diagram of experimental apparatus.

The testing procedures can be summarized as follows:

1- The coil is evacuated and then saturated with the desired displaced fluid.
2- The coil connected to displacing pump and the displacement process is stared with the desired flow rate.
3- The effluent sample is taken at each 0.026 of pore volume injected fore coil #1 and 0.0196 pore volume for #2.
4- The effluent is tested by Refractive index and the concentration of displacing fluid is measured, the measurements continued till the concentration become 100 % (vol/vol).

All measurements are conducted at constant temperature of 20^0 C.

3. MATERIALS USED

Kerosene and Gas oil are used as displacing fluid and seven hydrocarbon liquids of high purity (spectroscopic grade) are the displaced fluids. The properties of these fluids are given in table 2.

4. SCOPE OF THE EXPERIMENTS

Two sets of experiments have been conducted to evaluate the major factors that affect the dispersion during liquid-liquid miscible displacement. The total number of test is 103. During the first set of expriments, coil#1 represents the porous media and kerosene is the displacing fluid. The second is accomplished with coil#2 and gas oil as a displacing fluid. The concentration of kerosene and gas oil is measured by refractive index apparatus. Six flow rates were applied during the experiments which are 2.6, 5.2, 10.4, 20.8, 31, 2 and 41.6 cc/hr. The experiments covers a wide range of interstitial velocities (0.00554-0.1173 cm/sec) and viscosity ratios of (o.106-0.71).Table 3 is a sample of results for Q = 5.2 cc/hr. and kerosene as a displacing fluid.

5. RESULTS AND DISCUSSION

5.1. CONCENTRATION- TIME PROFILE

Fig.2 is a sample of displacing fluid concentration versus pore volume injected relationship. It can be considered as concentration-time profile. The main features of all concentration- pore volume injected are:

1- The transition zone between the displacing and displaced fluid follows the S-shape as the concentration increase from zero to 100%.This phenomena is attributed to continuous mixing rather than piston drive.
2- The 50% concentration of the displacing fluid corresponds to one pore volume injected.
3- The curve is symmetric around PV=1.

5.2 DETERMINATION OF DISPERSION COEFFICIENT

The volume modifying function U is calculated using Eq.(4) and correlated graphically with concentration of displacing fluid as illustrated in **Fig.3**. The dispersion coefficient is determined by Eq.(3).

5.3 EFFECT OF INTERSTITIAL VELOCITY

The results showed that dispersion coefficient increases as interstitial velocity increases due to increasing of mixing rate as viscosity ratio remain unchanged.

5.4 EFFECT OF VISCOSITY RATIO

The viscosity ratio is the ratio between viscosities of the displaced fluid to the displacing fluid. The results showed that the dispersion coefficient is influenced by this ratio. Table 4 and table 5 gave a clear ideas related to the effects of both viscosity ratio and interstitial velocity as represented by flow rates on dispersion coefficients

5.5 EFFECT OF HYDROCARBON TYPE

The results show an increase in magnitude of dispersion coefficients of both kerosene and gas oil as the molecular weight of displaced fluid of paraffinic base increase, same behavior does not appear for fluids of aromatic base.

6. CONCLUSIONS

1-Breakthrough of displacing fluid is shown before one pore volume is injected.

2-All runs result in breakthrough of 50% concentration of displacing fluid as one pore volume is injected.

3-The rate of mixing increases as the interstitial velocity of displacing fluid increases.

4-The dispersion coefficient is influenced by viscosity ratio.

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NOMENCLATURE

C: Concentration of displacing fluid, Vol./Vol.

Erfc: Complementary Error Function.

K: Dispersion Coefficient, cm^2/s.

L: Length of Porous Media, cm.

Q: Flow Rate cc/hr.

T: Time Required to inject One Pore Volume.

T: time.

U: Volume Modifying Function,

V_i: Volume Injected, cc.

V_P: Pore volume cc.

Φ: Porosity, fraction.

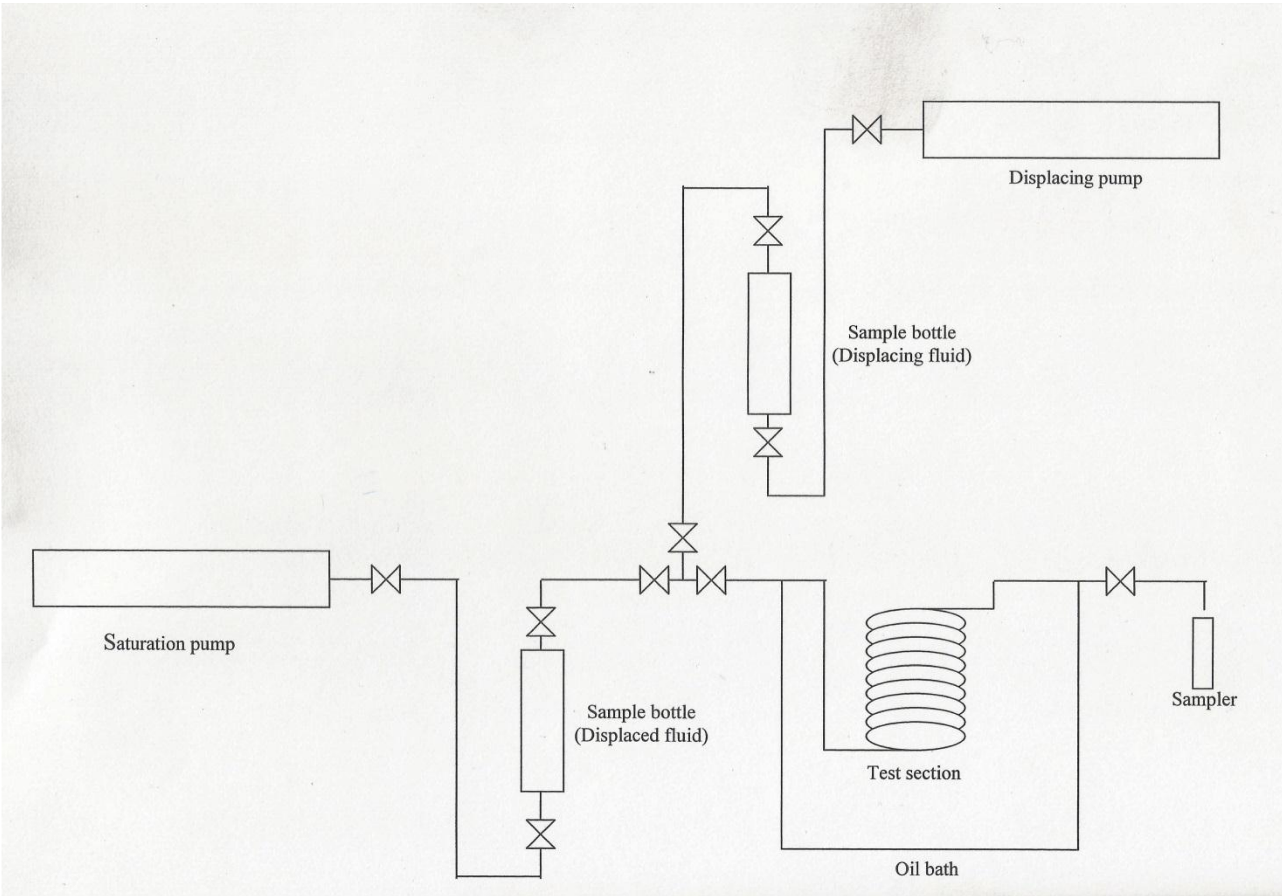

Figure 1. Schematic diagram of experimental apparatus.

Table 1. Properties of test-section

	length cm	Porosity Fraction	permeability Darcy	Pore volume cc
Coil #1	406	0.321	10	40
Coil #2	406	0.425	12	53

Table 2. Physical properties of displacing and displaced fluids at T= 20 ^{0}C.

Fluid	Dynamic Viscosity(Centi- Poise)	Refractive Index
Kerosene	1.281	1.44
Gas Oil	4.43	1.4737
n-Decane	0.91	1.411
n-Nonane	0.711	1.40561
Xylene	0.69	1.498
Benzene	0.652	1.5011
Toluene	0.59	1.497
Octane	0.542	1.39745
Heptane	0.409	1.38764

Table 3. Displacing fluid concentration (Coil #1,Q=5.2 cc/hr)

PV injected	U	Kerosene concentration(%) when the displaced fluid is						
		Heptane	Octane	n.Nonane	n.Decane	Benzene	Toluene	Xylene
0.6955	2.3092	0	0	0	0	0	0	0
0.7215	2.0736	0	0	0	0.5	0	0	0
0.7475	1.847	0	0	0.8	0.97	0.58	0	0.65
0.7735	1.6288	0	0	1.9	1.9	1.45	1	1.5
0.7995	1.4182	0.3	0.6	3	4	2.8	2.5	3.4
0.8255	1.2147	1.2	2	4.8	6.3	5.5	5	5.7
0.8515	1.0178	3	4	6.5	10	9.2	9	10
0.8775	0.827	5.9	7.65	11	15	15.1	15	16
0.9035	0.6421	11	13	17	20.9	22.8	22.15	23
0.9295	0.4625	19.1	21	24	28	31.9	30	32
0.9555	0.2879	29	30	32.4	35.25	41.95	41.8	42
0.9815	0.1181	42	41	42	44	53.4	52	54
1.0075	-0.0472	54.7	52.37	52	53.11	62	62	63
1.0335	-0.2084	66	63	62.1	61	72	71	72
1.0595	-0.3656	77.66	73	70	68.4	79	79.22	79.83
1.0855	-0.519	85	81.23	78	74	85.1	85.25	85.2
1.1115	-0.6689	90	88	84	80.6	90	90	90
1.1375	-0.8153	95	92	89	85.25	93.5	93.7	93.6
1.1635	-0.9586	97.8	95.6	93	89	96.2	96.45	96
1.1895	-1.0989	99	97.7	95	92	98	98.1	97.5
1.2155	-1.2362	99.5	99	96.6	94.5	99.2	99	99
1.2415	-1.3708	100	100	98.6	96.37	100	100	100
1.2675	-1.5027			99	97.5			
1.2935	-1.632			100	98.5			
1.3195	-1.759				99.3			
1.3455	-1.8838				100			

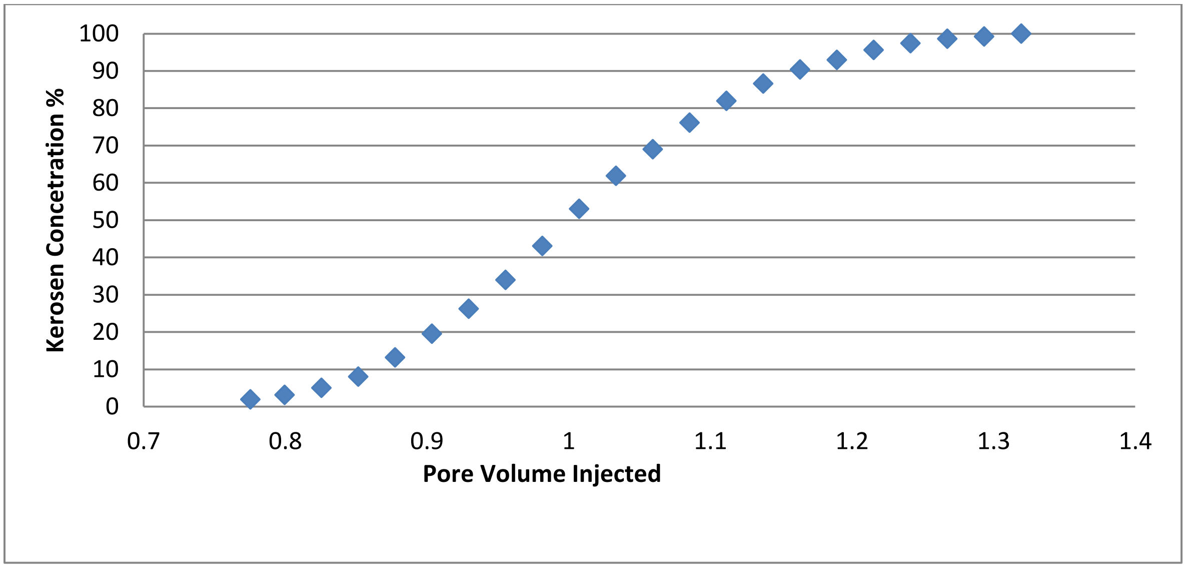

Figure 2. Kerosene concentration-pore volume injected(Coil #1-Displaced fluid n Decane – Q=2.6 cc/hr.)

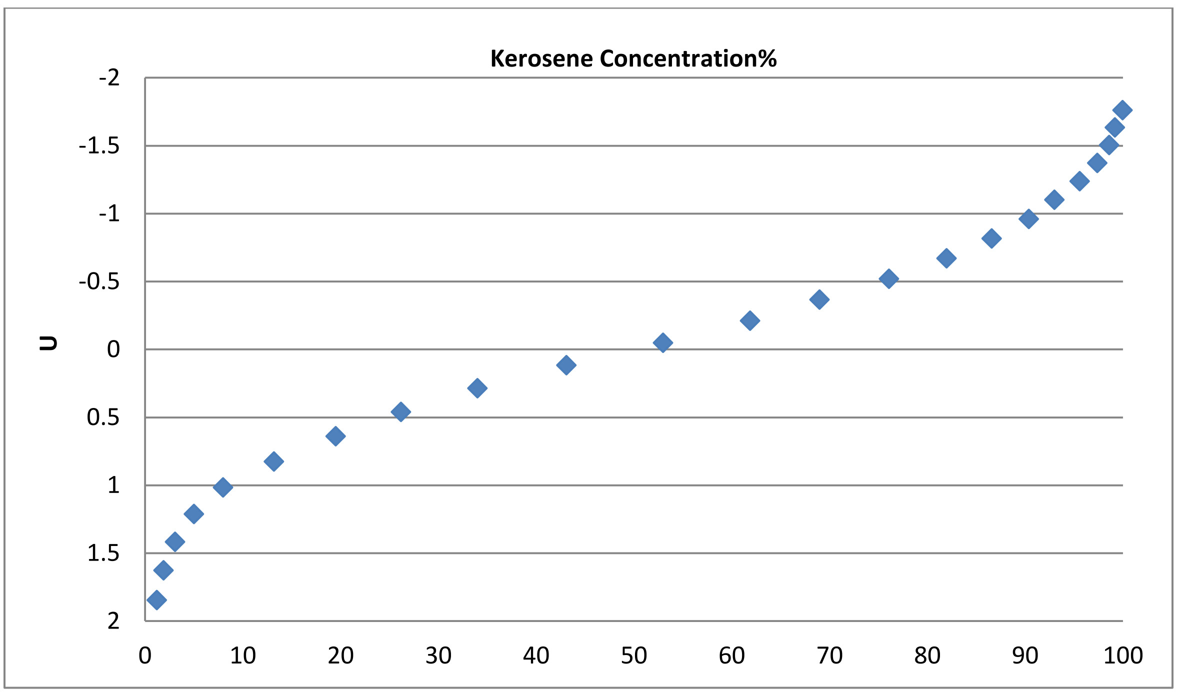

Figure 3. Volume modifying function versus kerosene concentration(coil#1,Q=2.6 cc/hr)

Table 4. Dispersion Coefficient of Kerosene (Coil#1)

Displaced Fluid	Viscosity Ratio	Dispersion Coefficient					
		Q=2.6 cc/hr	Q=5.2 cc/hr	Q=10.4 cc/hr	Q=20.8 cc/hr	Q=31.2 cc/hr	Q=41.6 cc/hr
Heptane	0.32	0.0089	0.0193	0.0416	0.0894	0.14	0.1923
Octane	0.423	0.012	0.025	0.057	0.118	0.1875	0.2621
n.Nonane	0.555	0.0157	0.0337	0.0726	0.156	0.2445	0.336
n.Decane	0.712	0.02	0.046	0.098	0.205	0.321	0.441
Benzene	0.509	0.0148	0.03	0.067	0.14	0.225	0.31
Toluene	0.46	0.0132	0.0284	0.0612	0.132	0.206	0.29
Xylene	0.538	0.015	0.031	0.071	0.15	0.2398	0.3295

Table 5. Dispersion Coefficient of Gas oil (Coil#1)

Displaced Fluid	Viscosity Ratio	Dispersion Coefficient				
		Q=2.6 cc/hr	Q=5.2 cc/hr	Q=10.4 cc/hr	Q=20.8 cc/hr	Q=31.2 cc/hr
Heptane	0.106	0.00303	0.00653	0.014	0.0302	0.0473
Octane	0.14	0.00398	0.00856	0.0184	0.0396	0.062
n.Nonane	0.1815	0.00513	0.011	0.0238	0.0511	0.08
n.Decane	0.24	0.00693	0.0149	0.032	0.07	0.1078
Benzene	0.1625	0.0046	0.01	0.0216	0.0464	0.0727
Toluene	0.1516	0.0043	0.0093	0.019	0.043	0.0673
Xylene	0.1758	0.005	0.0108	0.0232	0.049	0.0781