Effects of Wettability on the Distribution and Mobilization Mechanism of Residual Oil During Immiscible Displacement

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ABSTRACT

The interaction between the fluid and the rock surface may affect the wettability of the reservoir. The wetting characteristics of the reservoir influence the fluid distribution and flow behaviour which in turn influence the oil recovery efficiency. Majority of the studies previously conducted used uniform wetting condition of either water-wet or oil-wet. Microscopic visual observation of the oil-water distribution and the residual oil mobilization events have been conducted using etched glass micromodel. The location of water and oil blobs was observed and the size, shape and structure of the blobs were examined. From these examinations some insights of fluid distribution and mobilization mechanism were obtained. The present study also incorporates wettability conditions such as fractional-wet and mixed-wet.

INTRODUCTION

Before the 1950's oil reservoirs were thought to be water-wet. Later it was discovered that oil reservoirs can have a wide range of wettability; from strongly water-wet to intermediate-wet and oil-wet. Some reservoirs may even have a non-uniform wettability called mixed-wet. Reservoir wettability is more complex than was thought before (Treiber, 1972).

Most earlier microscopic immiscible displacement studies used water-wet and oil-wet porous media (Ahmad Kamal Idris, 1990), (Dullien et al, 1990), (Chatzis et al, 1983, 1988), (Yadav et al, 1987), (Wardlaw, 1982). For water-wet porous media the investigators used clean etched glasss or sandstone. Unconsolidated packs of sand or glass beads are also water-wet. Sandstones or glass beads were treated with oil wetting agent like organochlorosilane solution in order to get oil-wet porous media. An intermediate-wet condition was obtained by aging the porous media in crude oil. An oil-wet media can be produced by packing polytetrafluoroethylene (PTFE) beads. It is relatively easy to get a uniformly water-wet and oil-wet porous media.

As more mixed-wet reservoirs are discovered, there is a need to study fluid distribution and flow behaviour in this system. There is yet no detailed systematic study on fluid distribution and fluid flow behaviour in non-uniform wettability condition done at microscopic level. There is a theory on how fluid are distributed and how residual oil is mobilized in mixed-wet media. This theory first postulated by Salathiel (1973), states that residual oil is mobilized through the continous oil-wet pathways or channels present in mixed-wet porous media. But there is no experimental verification of the theory. This study aims to investigate the fluid distribution and flow behaviour especially in fractioanal-wet and mixed-wet conditions.

MATERIALS AND METHODS

This study is done at microscopic scale. The idea is to observe the fluid location and events taking place during and at the end of immiscible displacement at the pore scale. A two-phase system of oil and water is used. Distilled water and n-decane represented reservoir water and reservoir oil respectively. The porous media is a network of etched glass micromodel. The schematic flow apparatus is shown in Figure 1. The fluids are dyed to distinguish between water and n-decane. Water is dyed blue while n-decane is dyed red.

A variety of wetting conditions is obtained by the following methods. Water-wet media is obtained by using cleaned glass micromodels or cleaned glass beads. An oil-wet condition is established by using teflon beads and by treating glass beads with organochlorosilane solution. A weakly water-wet media is obtained by aging the micromodel in crude oil. An oil-wet condition is also established by treating the micromodel with asphaltene dissolved in toluene. A mixed-wet condition is obtained by using micromodel which is at irreducible water saturation and flowing organochlorosilane solution through it.

RESULTS AND DISCUSSION

The properties of the glass micromodel is given in Table 1 while the properties of the fluid is shown in Table 2. The flow parameters in the experiments is given in Table 3. Figures 2a, 2b, 2c and 2d show water and n-decane distribution in four different wettability conditions; water-wet, oil-wet, fractional-wet and mixed-wet. Photomicrographs that show similar fluid distributions as shown by Figure 2 were obtained. For water-wet condition (Figure 2a), the pore surface is covered with water. For the oil-wet case, the situation is reversed where the pore surface is covered with n-decane (Figure 2b). The case for non-uniform wettability is shown by Figure 2c and Figure 2d. These two figures show that some surface is wetted with water while some surface is wetted with n-decane. Figure 3a, 3b and 3c show the distribution of water and n-decane at the early stage, middle stage and at the end of water injection process. In these figures water is injected from the left. More residual oil blobs is seen in oil-wet case for a waterflood process. Oil recovery by waterflooding is lower in oil-wet condition than in water-wet condition. The residual oil is trapped in the middle of pores or at the pore throats by the mechanism of by-passing and snap-off.

From the photomicrographs, the fluids distribution at various wetting conditions can be seen. These wetting conditions are water-wet, oil-wet and fractional-wet. Various structures of oil blobs like single blobs, multiple blobs or aggregates are seen. From the immiscible displacement experiments using glass micromodel the mobilization and trapping phenomena like snap-off and by-passing are clearly seen. Thus the finding of previous researches was confirmed. Also confirmed is the presence of continous oil-paths existing in mixed-wet porous media. Mixed-wet condition condition produces high oil recovery if water injection is continued to high volume.

CONCLUSIONS

1. The distribution of water and oil and their flow behaviour in uniform wetted porous media and in the non-uniform wetted porous media are significantly different.

2. Wettability plays a strong influence in fluid distribution and fluid flow behaviour.

3. During immiscible displacement residual oil is trapped by the process of "by-passing" and by "snap-off" mechanism.

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ACKNOWLEDGEMENTS

We gratefully acknowledged the financial support provided by the Malaysian Government through the IRPA Programme. Special thanks go to UTM's technicians; Abu Samah, Hidir, Roslan and Nordin for their help in the laboratory work.

Table 1: Properties of the etched glass micromodel

Type of Network Pattern:	Heterogeneous network
Length:	120 mm
Width:	54 mm
Pore size:	20 - 200 micron
Pore depth:	100 micron (approximate)
Coordination Number:	4 (average)
Pore Volume:	0.25 ml
Absolute Permeability:	53.7 Darcies

Table 2: Properties of fluids used (at 28 ^{0}C)

Properties	Distilled Water	N-Decane
Density, gm/ml	0.99	0.73
Viscosity, cp	1.0	0.9
Surface Tension, mN/m	69.6	24.0
Interfacial tension (IFT) for n-decane/water = 15 mN/m		

Table 3: Flow parameters

Flow rates, :	3.33 μl/min
Estimated darcy velocity:	1.85 x 10^{-3} m/s
Water viscosity:	0.55 mPa s
Capillary number:	(1.85 x 10^{-3} x 0.55)/15 = 6.78 x 10^{-5}
Viscosity ratio water displacing n-decane:	1.1
Viscosity ratio n-decane displacing water:	0.9

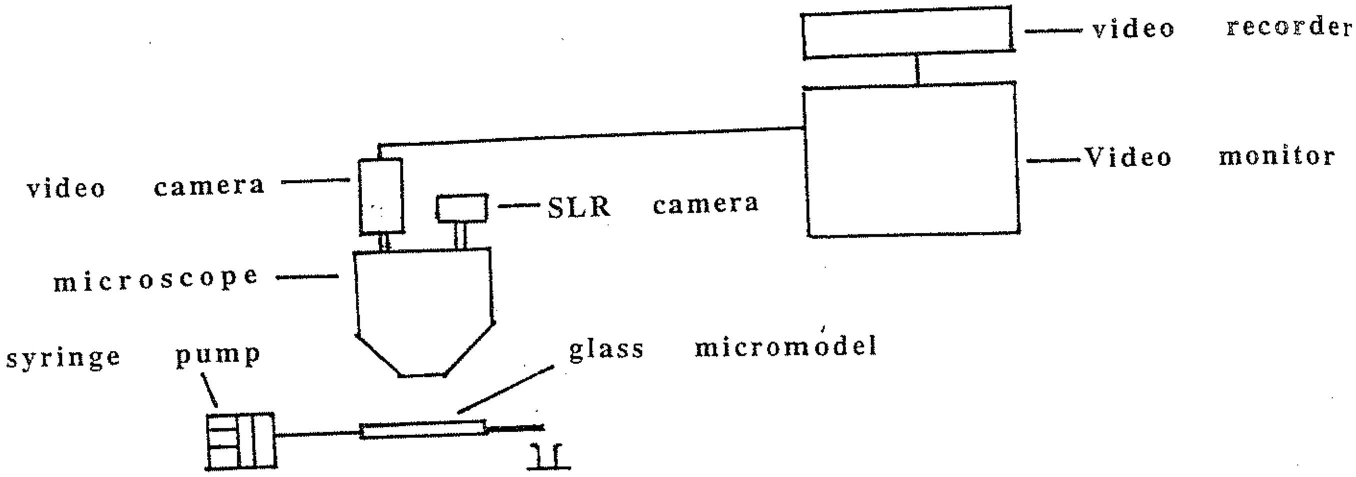


Figure 1: Schematic diagram of micromodel visualization apparatus

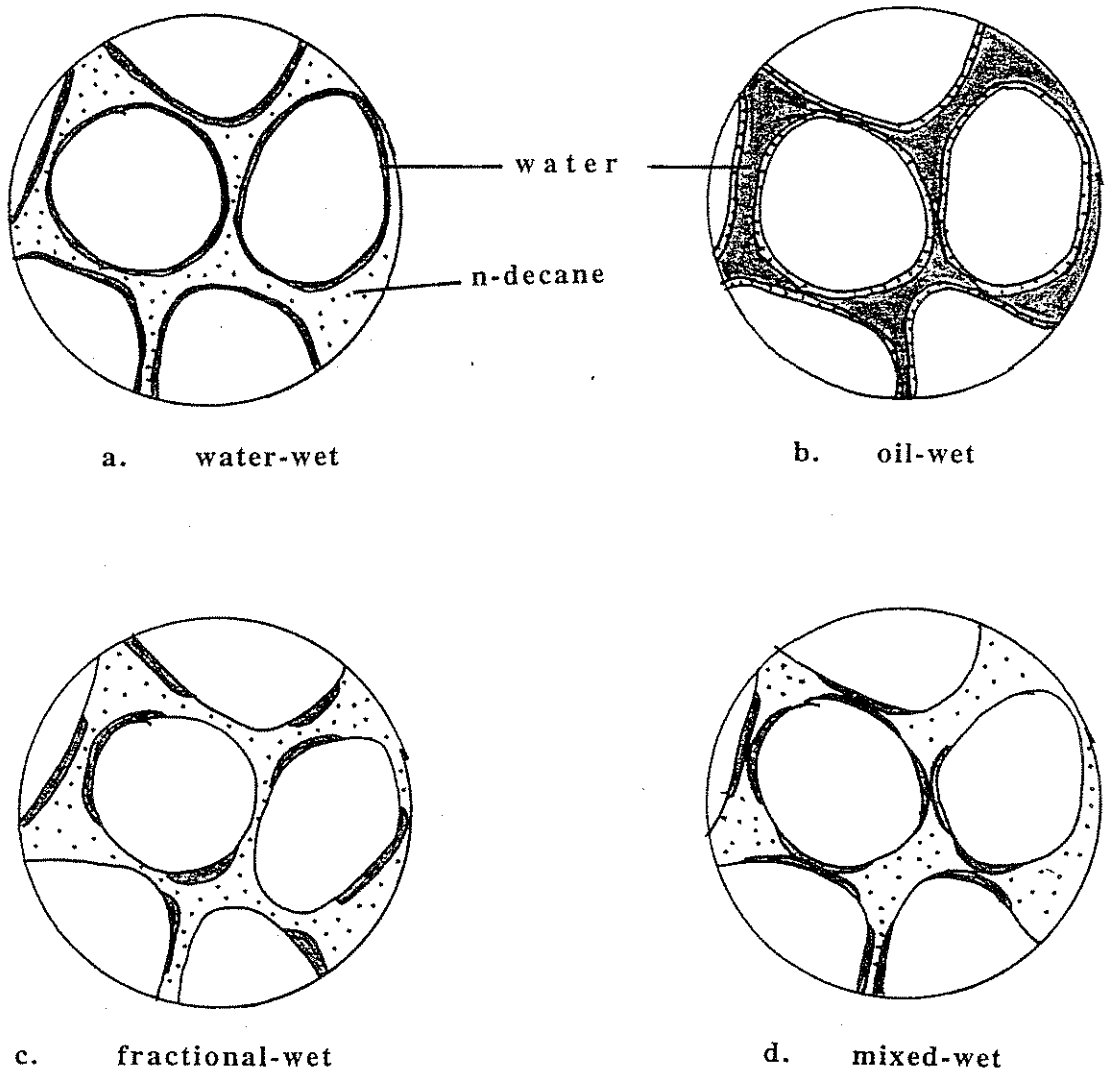
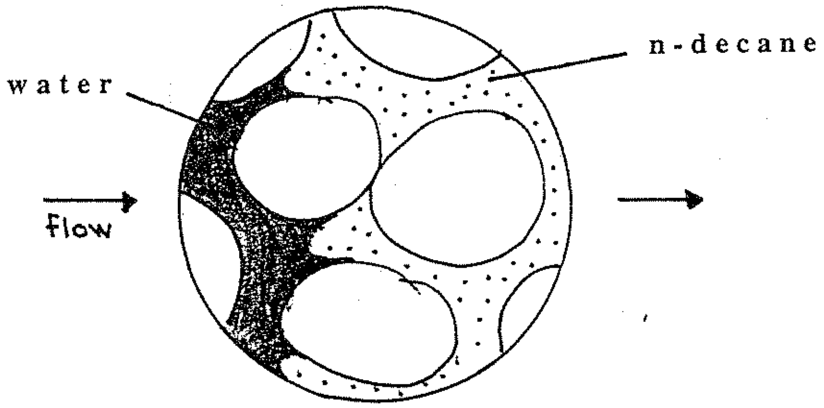
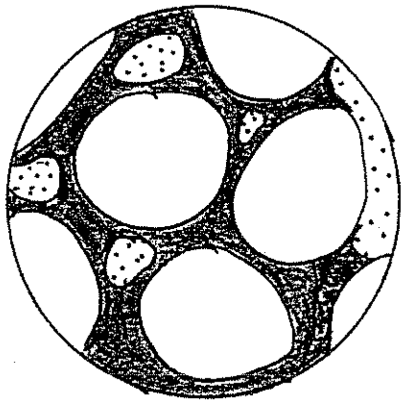


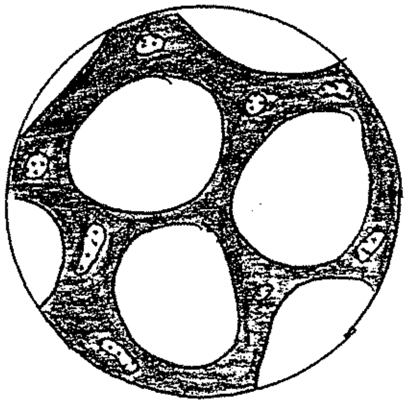
Figure 2: Water and n-decane distribution in the pores at different wetting conditions



a. early stage (0.2 pore volumes water injected)



b. middle stage (0.6 pore volume water injected)



c. end stage (1.2 pore volumes water injected)

Figure 3 : Water and n-decane distribution at different stages of water flooding — Water-wet case