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Enhancing the oil recovery of heterogeneous reservoirs underlaid by tarmat layer

Abdullah Alfayfi, Osama Elmahdy, and Abiodun Matthew Amao

King Saud University, Petroleum and Natural Gas Engineering Department, Riyadh, Kingdom of Saudi Arabia

ABSTRACT

Oil reservoirs are sometimes underlain by thick tar mat layers at the oil-water contact. Such tar mats are found in many major oil reservoirs in the world and, particularly, in the Middle East. Tar mats create several problems in the extraction process during the recovery stages. This study is aimed at investigating the effectiveness of chemical (solvents) method on enhancing the crude recovery from such reservoirs. This study was carried out using different samples of heterogeneous rocks closer in description to those of the real ones in the region. The implications of tar mat layers on oil recovery were examined with different flooding scenarios including water flooding and a combination of water with different solvents. All experimental runs were conducted at 3500 psi overburden pressure, 1500 psi pore pressure, and 60°C temperature conditions. Results show that the recovery was reduced by 27.34% and 24.9% with tar present in the system for the samples used. The recovery increased by around 6.86% and 7.0% when a combination of water and toluene were used with tar present. Also, the recovery increased by around 2.67% and 2.21% when a combination of water and chloroform were used.

KEYWORDS

Saudi Arabia; tar mat; oil recovery; heterogeneous

1. Introduction

Many oil reservoirs are characterized by the presence of a highly viscous hydrocarbon layer (tar mat) at the OWC. Such tar mats are found in many major oil reservoirs in the world and, particularly, in the Middle East. This tar mat barrier is in general very thick and could be as thick as the oil column in some reservoirs (Osman, 1985). The presence of tar deposits at the OWC in a tar mat reservoir can have serious adverse effects on the effectiveness of natural water drive as well as on secondary recovery projects. Bashbush et al. (1983) discussed methods of water flooding of El Bundug field in the offshore area of Abu Dhabi and Qatar. In this reservoir, both geologic and reservoir studies showed that the tarmat layer was acting as a barrier to fluid movement without being a complete seal. Wilhelms and Larter (1994) defined tar mat as reservoir zone containing petroleum strongly enriched in asphaltenes, low in paraffin, and aromatics content relative to the related oil leg. Tar mats is believed to be formed as a result of water washing, natural deasphalting, biodegradation, and gravity segregation, which results in grade variations in the composition with changes in depth (Hirschberg, 1988). The in situ viscosity of tar is over 10,000 cp with gravity lower than 10°API (Nascimento and Gomes, 2004). In the Uthmaniya region, Saudi Arabia, tar mats tend to stretch up to 15 miles with a thickness of 500 ft with reserves estimated over 2.3 billion barrels (Al-Bazzaz, 2014). Shamaldeen and Ali (1985) tested different recovery techniques in laboratory models simulating tar mat reservoir. They also studied the performance of tarmat waterfloods. They concluded that communication between aquifer and the oil zone increases oil recovery. A

CONTACT Abdullah Alfayfi aalfayfi@ksu.edu.sa King Saud University, Petroleum and Natural Gas Engineering Department, Box 800, Postal Code 11421, Riyadh, Kingdom of Saudi Arabia.

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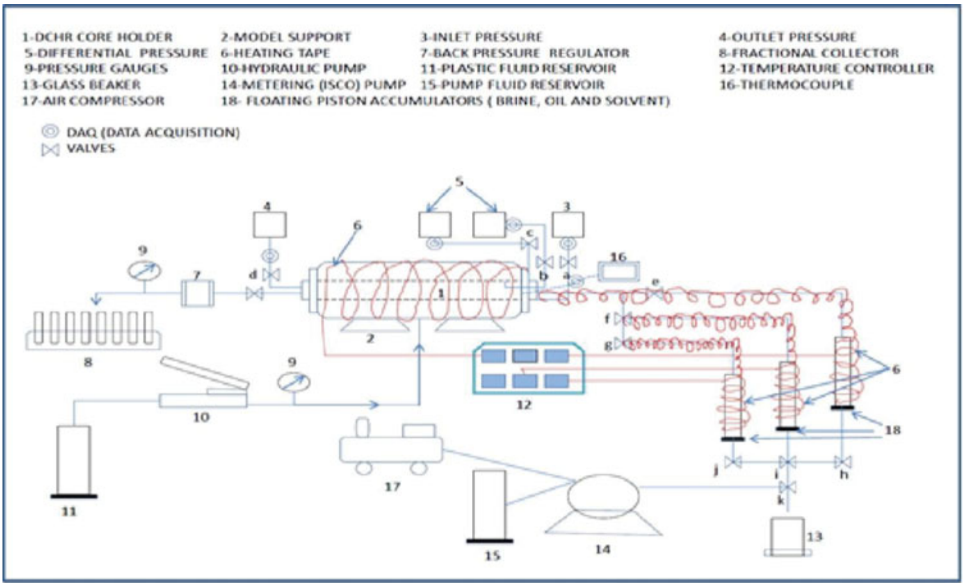

Figure 1. Schematic diagram of core flooding system CFS-200.

study on cold water flooding in a tar mat reservoir laboratory model (composite Berea sandstone core) was carried out by Abu-Khamsin (1993). The results illustrate that as the viscosity and the thickness of the tar zone increased, the oil recovery increased. Another study of oil recovery from a tar mat reservoir was conducted by Okasha (1998). The results of their study show that while oil recovery from hot water displacement was lower than that from cold water displacement in the absence of tar, hot water led to the recovery of substantially more oil than cold water in the presence of a tar-mat. An important factor affecting oil recovery was the injection rate for all hot water flooding schemes; lower injection rates increased oil recovery. Al-Mansour et al. (2014) investigated three enhanced oil recovery (EOR) methods; their results showed that the oil recovery significantly increased as temperature increased.

2. Experimental

2.1. *Materials used*

All experiments were conducted using core plugs from Sarah sandstone formation outcrops in Al-Helalliah town, Al-Qassim province, Saudi Arabia. Fluids were Ratawi Hout crude oil as oleic phase and 1% salinity brine solution composed of 58% NaCl, 32% $MgCl_2$, and 10% $CaCl_2$ in distilled water as aqueous phase. The tar phase was prepared by evaporating a batch of heavy Ratawi crude oil until a viscosity greater than 30,000 cp was reached at room conditions. Toluene and chloroform were selected as solvents based on a solubility test carried out in the laboratory.

2.2. *Setup*

A Core Flooding System CFS-200 was used to measure the permeability and for displacement experiments using water and a combination of water and solvent. A schematic of the core flooding setup used is shown in Figure 1.

2.3.1. *Tar saturation setup*

Saturation of cores with tar was carried out using a special tar saturation setup. A schematic of the tar saturation setup used in this study is shown in Figure 2.

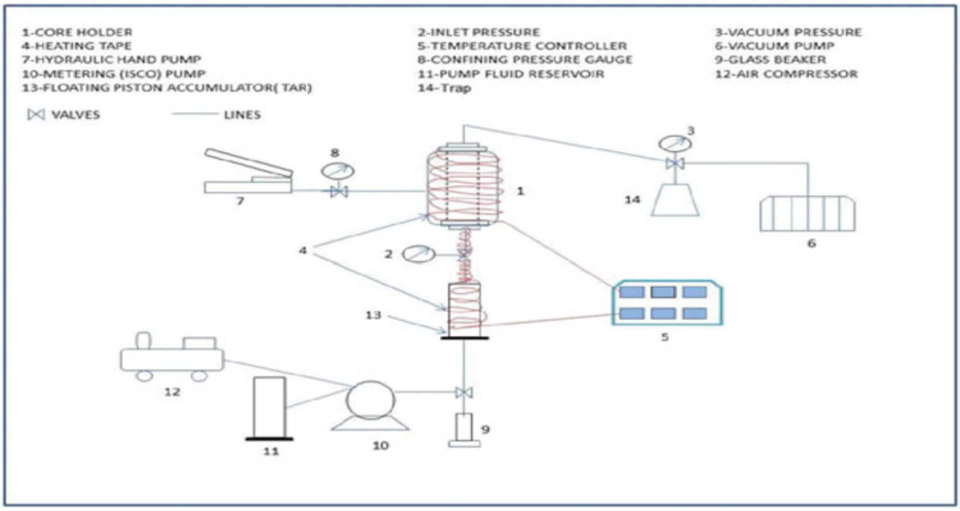

Figure 2. Schematic diagram of Tar saturation setup.

2.3. *Procedure*

The core holder was disconnected and sample representing tar layer was placed at the inlet side of the core holder followed by the sample representing the oil zone. Silk screen mesh was placed behind core plugs to prevent lines clogging by sand grains. The composite core was loaded into the rubber sleeve, and the core holder was assembled in the experimental setup as shown in Figure 1. Experimental runs were conducted based on the following steps:

1. The experiments were conducted at a temperature of 60°C, and the core holder, flow lines, and the fluids were allowed to equilibrate at this temperature before the experiment commenced.
2. A confining pressure of 3500 psi and back-pressure of 1500 psi were applied in all experimental runs.
3. After temperature equilibration, injection of fluids (brine, oil and solvent) was started at a constant rate of 2.0 cc/min and was continued for 5 PV (pore volumes).

Table 1. Physical properties of the fluids at 22°C.

Fluid name	Viscosity, mPa.sec	Density, g/cc
Brine	1.15	1.005
Ratawi crude oil	39.59	0.891
Heavy Ratawi oil	6500	0.924
Tar	30,000	1.062
Toluene	0.6	0.866
Chloroform	0.57	1.474

Table 2. Petrophysical properties and displacement calculations.

Sample name	Length, cm	Pore volume, cc	Porosity, %	Permeability, md	Irreducible water saturation, %	Oil recovery factor, %
A1	10.10	30.33	25.03	371.3	33.81	62.64
A2	10.05	27.46	26.64	325.2	36.1	65.53
A6	8.06	24.93	26.54	517.2	36.56	68.1
A7	7.80	23.81	27.73	412.5	23.4	53.95
A10	10.25	27.94	26.63	442.7	34.6	65.77
A11	11.06	31.55	26.39	502.2	33.6	64.42

Table 3. Characteristics and petrophysical properties of the selected samples.

	Sample name	Length, cm	Porosity, %	Permeability, md
	A1	10.10	25.03	371.3
	A11	11.06	26.39	502.2
	T1	3.20	27.29	400.0
A5	**T4**	2.50	27.29	400.0

4. After each run was completed, the core holder was dismantled and tar displacement vessel was estimated carefully. Core plugs making up the oil and tar zones were then extracted and cleaned for the next run using a solvent extractor apparatus.

3. Results and discussion

3.1. *Solubility of tar*

Solubility tests were carried out to determine the response of the used tar to solvent type. Standard solubility tests were conducted at room temperature (22°C). Toluene and chloroform represent the most appropriate solvents, based on their ability to dissolve tar (toluene and chloroform dissolved tar at the minimum volume and time).

3.2. *Fluids properties*

The physical properties of the fluids (oil, brine, tar, and solvents) at 22°C summarized in Table 1.

3.3. *Flooding results*

The data summarized in Table 2 lists the characteristics and displacement of core samples that were selected for use in flooding experiments. Table 3 shows the characteristics and petrophysical properties

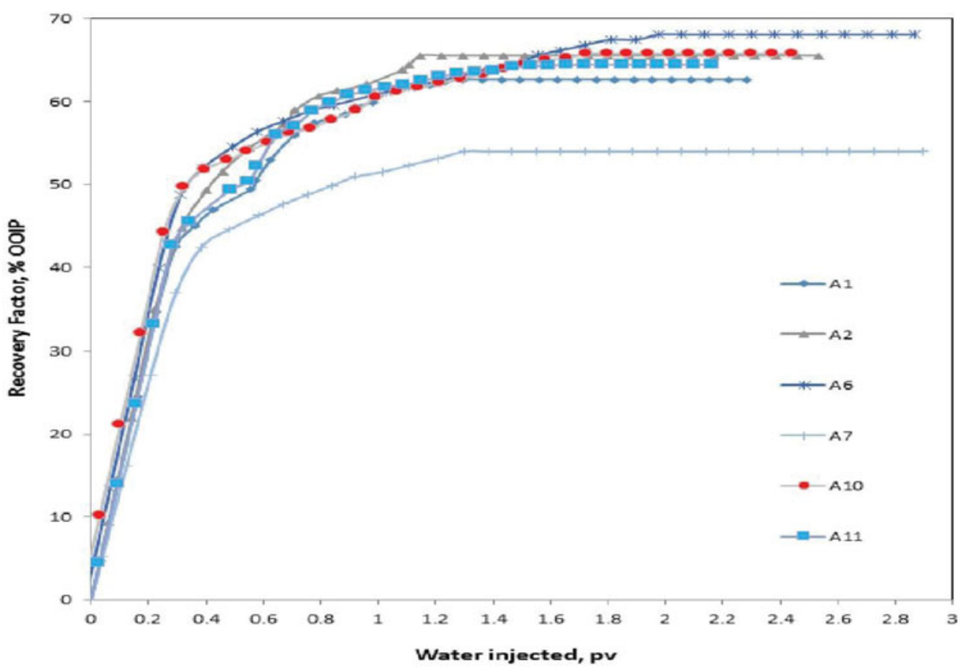

Figure 3. Recovery measurements of six samples (water flooding without tar) @ 60°C and 3500 psi conditions.

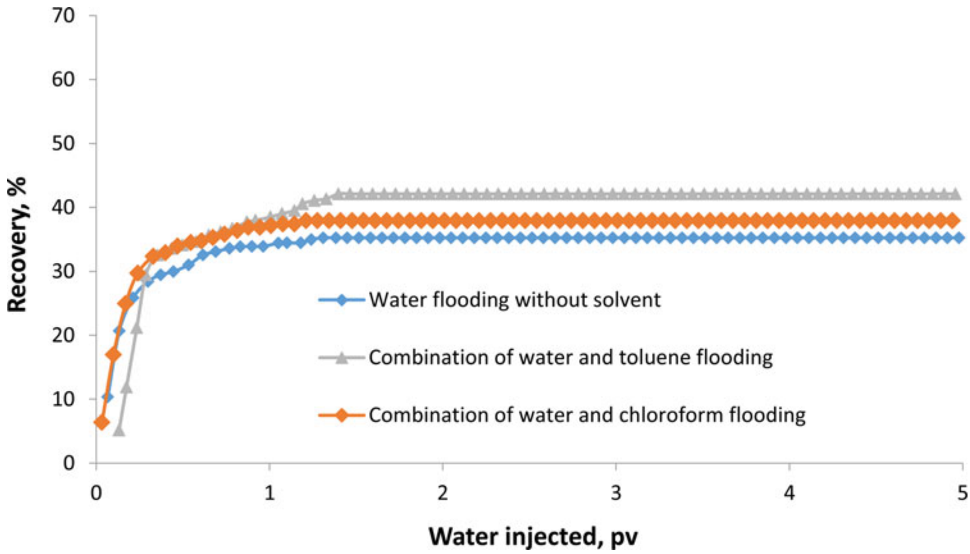

Figure 4. Effect of solvent and solvent type on oil recovery for core A1.

of the two core samples (A1 and A11) that were selected from the six core samples based on the length and irreducible water saturation for use in the flooding experiments in presence of tar. Core sample A5 was divided to two small samples (T1 and T4), and saturated with tar. All the oil recovery curves are shown in Figure 3. In all of the waterfloods, 1.5∼2.0 PV of water injection were required to reach the ultimate recovery. The recovery of the 6 runs without tar layer range from 62.6% to 68.1% (except one run, which has 53.95%) this is a result of the heterogeneity of the samples. The recovery of core samples A1 and A11 were 62.60% and 64.40%, respectively.

3.4. *Effect of solvent and solvent type on oil recovery*

In this study, two solvents toluene and chloroform driven by water were employed. (Figures 4 and 5) show graphs of the hydrocarbon net recovery, R, versus water injected volume. It can be seen that R

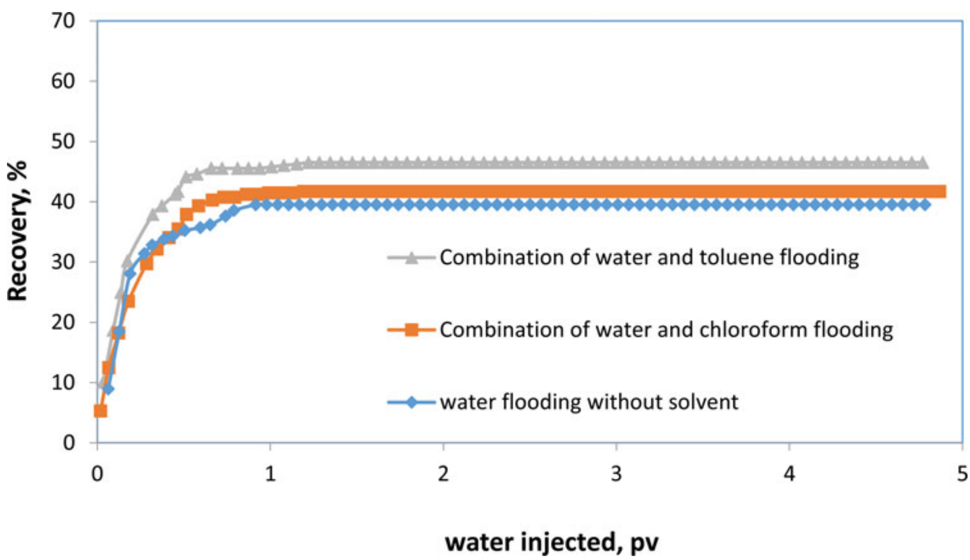

Figure 5. Effect of solvent and solvent type on oil recovery for core A11.

increases when the solvents used. It is observed from (Figures 4 and 5) that the combination of water and solvent flooding (toluene) gave a recovery of 42.12% for core A1 and 46.5% for core A11 in presence of tar while the combination of water and solvent flooding (chloroform) gave a recovery of 37.93% for core A1 and 41.71% for core A11 in presence of tar also, which was substantially greater than that of the other flood (water alone) which gave recovery of 35.26% and 39.5%, respectively. This is a result of the injection of a solvent slug followed by water flooding which dissolves the tar layer and establishes adequate communication between the water and the oil zone. Oil recovery when the combination of water and toluene flood was substantially greater than that of the water alone (increased by 6.86% for core A1 and 7% for core A11) and also when chloroform was used. The oil recovery factor when a combination of water and toluene flood gave the best result (incremental recovery) from the other flooding scenarios.

4. Conclusions

The following conclusions can be drawn based on the previous results and discussions:

1. The injection of a solvent slug followed by water flooding disperses the tar layer and establishes adequate communication between the oil and the water zone.
2. The type of solvent as an affected on the recovery factor (higher hydrocarbon recoveries are obtained with combined water and toluene flooding than with water and chloroform flooding in the presence of tar).
3. The oil recovery with combined water and solvent (toluene) flooding was substantially larger than that with water alone in presence of tar (approximately 6.93%).
4. Toluene and chloroform were suitable solvents to dissolve and disperse the tar used in this study.

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References

Abu-Khamsin, S. A., Ayub, M., Al-Marhoun, M. A., and Menouar, H. K. (1993). Water flooding in a Tarmat Reservoir Laboratory Model. *J. Pet. Sci. Eng.* 9:251–261.

Al-Bazzaz, W. (2014). Modeling unconventional recovery of next generation (extreme heavy oil) deep tar-mat reservoir. SPE 172863, *SPE International Heavy Oil Conference and Exhibition*, Kuwait, Mangaf, December 8–10.

Al-Mansour, A. O., Al-Bazzaz, W. H., Saraswathy, G., Sun, Y., Bajoun, B., and Ralph, F. (2014). Investigation of the physical and chemical genisis of deep tar-mat oil and its recovery potential under different temperature. SPE 170059, *SPE Heavy Oil Conference*, Calgary, Canada, June 10–12.

Bashbush, L. A., Savage, W. K., Nagai, R. B., Gimito, T., Wakamiya, J., and Takizawa, H. (1983). A reservoir optimization study El Bunduq Field, Abu Dhabi, Qatar. SPE 11481, *Middle East Oil Technical Conference*, Bahrain, Manama, March 14–17.

Hirschberg, A. (1988). The role of asphaltenes in compositional grading of a reservoir's fluid column. *J. Pet. Technol.* 40:89–94.

Nascimento, J. d. D. S., and Gomes, R. M. R. (2004). Tar mats characterization from NMR and conventional logs, case studies in deepwater reservoirs, Offshore Brazil. *SPWL A 45th Annual Logging Symposium*, Noordwijk, the Netherlands, June 6–9.

Okasha, T. M., Menouar, H. K., and Abu-Khamsin, S. A. (1998). Oil recovery from Tarmat reservoirs using hot water and solvent flooding. *J. Can Pet. Technol.* 37(4).

Osman, M. (1985). An approach to predict Tarmat breakdown in Minagish Reservoir in Kuwait. *J. Pet. Technol.* 37:2071–2075.

Shamaldeen, S. M., and Ali, S. M. F (1985). An experimental study of techniques for increasing oil recovery from oil reservoirs with tar barriers. SPE 13705, *Middle East Oil Technical Conference and Exhibition*, Bahrain, March 11–14.

Wilhelms, A., and Larter, S. R. (1994a). Origin of tar mats in petroleum reservoirs. Part 1: introduction and case studies. *Mar. Pet. Geol.* 11:418–441.2.

Wilhelms, A., and Larter, S. R. (1994b). Part II: formation mechanisms for tar mats. *Mar. Pet. Geol.* 11:442–456.