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Screening Guides for EOR Methods Under Reservoir Conditions

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ABSTRACT

Different Enhanced Oil Recovery (EOR) processes were investigated for their application in some selected Libyan reservoirs having similar rock and fluid properties. The study showed that out of the three processes (Miscible Drive, Thermal and Chemical) considered for EOR, miscible drive has more chance of applicability. The screening guides applied in the present study can be generalized for other reservoirs having different rock and fluid properties.

EOR PROCESSES CONSIDERED

Miscible Drive Processes

In a miscible displacement process, capillary forces are absent and consequently the microscopic displacement efficiency is close to ideal. It can be applied either as a secondary process or as a tertiary process to recover waterflood residual oil. The following miscible recovery processes according to the type of miscible agent were investigated (Ballard and Smith, 1972; Craig, 1970; Ali, 1977): (1) High pressure lean gas injection, (2) Enriched gas injection, (3) LPG injection, (4) Alcohol sludge injection, and (5) CO_2 injection.

Thermal Methods

The main purpose of heat injection in oil reservoirs is viscosity reduction of the heavy oil or evaporation of the residual light oil. The following thermal processes were considered (Ali, 1966; DeHaan and Schenk, 1961; Gates and Brewer, 1979; Ali, 1972): (1) Hot water injection in heavy/light oil reservoirs, (2) Steam drive in heavy/light oil reservoirs, (3) Cyclic steam injection (steam soak) in heavy/light oil reservoirs, and (4) In-situ combustion.

Chemical Processes

Chemicals added to the water drive in chemical-flooding processes aim either at a reduction of the capillary-trapping forces or at an improvement of sweep efficiency of the water drive. The following processes were considered (Bae and Petrick, 1977; Szabo, 1975; Sandiford, 1964): (1) Surfactant (Micellar) flooding, (2) Polymer flooding, (3) Caustic flooding, (4) Micro-emulsions, and (5) Foam flooding.

APPLICATION OF "RANKING CRITERIA" TO OIL FIELDS UNDER INVESTIGATION

The various EOR processes discussed above will have a chance of success if certain reservoir and fluid property requirements are met. These requirements are listed in Table 1. The table presents the current status of the various techniques as well as the purpose of a particular process. Whenever a reservoir meets most of the requirements of a certain EOR method, the conclusion should be that a further investigation is justified in order to decide if the EOR process is technically and economically viable for that particular reservoir.

The values of the various reservoir and fluid properties for the main oil fields considered in this study are given in Table 2. In the following section, the possible application of EOR processes in those reservoirs is further discussed.

DISCUSSION

Thermal Methods

At present virtually no hot water or steam drive projects are carried out at a depth below 4000 ft, as otherwise the maximum allowable reservoir pressure for a steam drive would be exceeded. Heat losses will be high at greater depths. The maximum reservoir pressure for in-situ combustion is 1500 Psi, while there is no restriction to the reservoir depth for this process. Some oil reservoirs under investigation meet these requirements such as Um-El-Foroud and E1-Nafoura. Inspite of the fact that the API gravity of the oil in Um-El-Foroud is very high (47^o) and that of El-Nafoura is medium (35.6^o), the application of thermal methods especially steam may lead to an increase in oil recovery. The expected improvement in oil recovery is due to the distillation and condensation of the light fractions present in these oils by the injected heat. Concerning the in-situ combustion techniques, there is no

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Table 1. Criteria of the different methods of enhanced oil recovery.

	Method	°API	Temp. °F	Pressure, Psi	μo CP	φ %	K md	Thickness ft	Depth ft	Lithology
Miscible Drive Methods	CO_2	30-45	250	2500 - 4500	5-10	-	-	10 - 500	> 3000	Sandstone & carbon. (L.S.)
	Enriched Gas	< 40	-	1500 - 3000	< 10	-	100	20 - 100	3000-6000	Sandstone & carbon. (L.S.)
	High Pressure Dry Gas	> 40	-	3000 - 6000	0.25-1.1	-	-	-	> 5000	-
	LPG	< 40		> 1300	5-10	-	50	-	2000-2500	Sandstone & carbon. (L.S.)
Thermal Methods	Steam Flooding	7-40	-	> 1000	-	≥25	> 50	> 10	< 4000	Sandstone
	In-Situ Combustion	< 40	-	> 1500	-	≥25	≥100	> 30	> 1000	Sandstone or carbonate. (L.S.)
Chemical Methods	Surfactant	≥25	250	-	up to 20	-	> 50	-	-	Sandstone
	Polymers	≥20	250-300	-	200-300	-	20-50	-	< 10,000	Sandstone & Limestone
	Micro-Emulsions	≥30	200	-	10-30	-	20-50	-	-	Sandstone or (L.S.) (S.S. is Preferable)

Table 2. Reservoir and fluid properties for oil fields considered in study.

Oil Field	°API	Temp. (°F)	u_o (CP)	O (%)	K (md)	Thickness (ft)	Depth (ft)	Pressure (psi)	Lithology	Driving Mechanism
UM-El Foroud:										
Bu Sharma(1)	47.0	136	0.6	22.4	45	6.0	1850	620	limestone	water drive, rock & fluid expansion
Bu Sharma(2)	47.0	136	0.6	22.4	35.8	8.0	1900	620	-do	-do-
El-Dahra	47.0	136	0.6	28.1	43	24.0	2000	620	dolomite	-do-
El-Nafoura	35.6	130	1.614	25.0	24	38.0	3000	1400	-	water drive
Zaggout	34.2	188	0.87	24.4	45	34.5	5885	2802	limestone	-do-
Bahi	43.3	150	0.7	28.0	150	103.2	2590	1188	carbonate	-do-
Ghani	41.0	185	0.405	26.5	30	58.7	5070	2357	dolomite	sol. gas drive
Misrab-Majed	39.6	239	0.41	17.1	163	44.4	9900	4897	sandstone	rock & fluid expansion
El-Rymal:										
Lower	37.0	271	1.52	9.0	13	239.0	13700	6125	-do-	sol. gas drive
Upper	31.0	285	4.07	17.0	370	160.0	10700	5009	-do-	water drive
Lahib	52.0	266	0.115	8.4	291	230.0	8545	4043	sandstone & quartz	water drive & sol. gas drive
El-Gabel	37.5	210	0.419	26.7	6.2	71.0	7100	3390	sandstone, quartz & shale	water drive, sol. gas drive & gas cap. drive
El-Fidaa	42.0	175	0.97	8-30	73	71.0	5100	2384	Dolomite	water drive
Entisar	-	-	-	22	200	-	8946	4000	sandstone	water drive & gas cap. drive

possibility for application due to the high API gravity of crude oil of reservoirs under consideration, besides other requirements.

Miscible Processes

The formation dip in the majority of reservoirs is low, and therefore stable displacement of the oil by either a lean gas, enriched gas, LPG or CO_2 drive can only be obtained at low offtake rates. The stability in the case of CO_2 injection can be improved by foam or alternate water/gas injection. The actual values of the maximum allowable offtake rates can only be obtained from appropriate reservoir simulation model studies, which are able to describe the dominant production mechanisms properly.

Some reservoirs meet the requirements for the application of high pressure dry gas injection as is the case in Entisar and Lahib oil fields. Other reservoirs as of El-Gabel are suitable for the injection of enriched gas as a miscible drive process.

Actually, oil production from Entisar oil fields is taking place by the injection of high pressure gas as a miscible drive process since the early stages of its productive life. The high pressure gas injection in this field is one of the successful EOR techniques applied in Libya.

Most of the requirements for the injection of CO_2 are fulfilled, especially in those reservoirs in which water injection is currently applied. The reservoir pressure (as a result of water injection) is suitable to create the miscibility between the oil and the injected gas.

Chemical Processes

In general, most of the ranking criteria for chemical flooding are not met in the reservoirs considered. The possibility of using polymers has been excluded mainly due to the low viscosity of the crude oils besides other requirements.

There is a limited possibility to use micro-emulsions in Um-El- Foroud, Zaggot, and Lahib oil reservoirs. Also, surfactants have limited chance for application in some oil reservoirs such as El-Romal oil field.

CONCLUSION

Several of the enhanced oil recovery processes could possibly be considered for oil reservoirs included in this investigation to increase their productivity. However, further investigation is necessary in view of the complexity of the EOR techniques and the oil reservoirs. Nevertheless, it can be observed from the ranking table (Table 1) that at the present state-of-the-art of EOR methods, the chance of a successful implementation of these processes in oil reservoirs under study, is limited in that group of methods namely miscible drive. High pressure dry gas, enriched gas as well as carbon dioxide can be used as miscible drive processes depending on the quality of oil and other reservoir conditions. However, the ongoing research and development for the EOR techniques, especially chemical methods, could yield promising results.

The application of ranking criteria presented in this paper can be extended to study the possibility of using EOR processes under different reservoir conditions.

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