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Feasibility of Increasing Oil Recovery by CO_2 Injection in Syrian Fields (Deir ez -Zour Region)

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Abstract

Oil-production from enhanced oil recovery (EOR) project continues to supply an increasing percentage of the world's oil, about 3% of the worldwide production

Now comes from (EOR), and this percentage is increasing with time, because of the conventual's oil production has continued to full and is not – currently – enough effective, therefore, the importance of choosing the "best" recovery method becomes increasingly important to petroleum engineers.

The objectives of this research: to present technical and economical feasibility for (EOR) by using miscible carbon dioxide (CO_2) in Syrian oil fields (Deirez-zour region, essentially A_{lm} field), so that CO_2-EOR improvement displaces oil left in place (after primary production and secondary water flooding which has been successfully injected in these fields for many years) via achieving several properties especially:

1) Reduction of oil viscosity,
2) Swelling of oil volume and
3) Acidic effect on rock.

The candidate A_{lm} field in Deirez-zour was studied in order to determine potential (EOR-CO_2) by knowing the A_{lm} characteristics (geological and engineering review) that adapted with CO_2 condition injection and presenting exhaustive screening, it was recommended that CO_2 miscible (water-alternative -gas) or CO_2-WAG has accepted as an effective technique for (EOR) with A_{lm} reservoir conditions.

The recovery factor predicted by CO_2 in A_{lm} about 12% OOIP (original oil in place), that mean about 32 MMBO (million barrels of oil).

Economical analysis: (capture, compression, transportation and injection costs), capital expenditures (CAPEX), operational expenditures (OPEX) were presented depending on previous and current onshore experience.

1-Introduction

For the last three decades, scientists have been searching for techniques to recover more oil from depleted reservoirs, which still contain as much as 50% of original oil in place (OOIP) after primary and secondary recovery, These techniques are known as EOR, so EOR is any method that increase oil production by using materials that are not part of normal pressure maintenance or water flooding operation, for example, natural gas can be injected into a reservoir to "enhance" or increase oil production

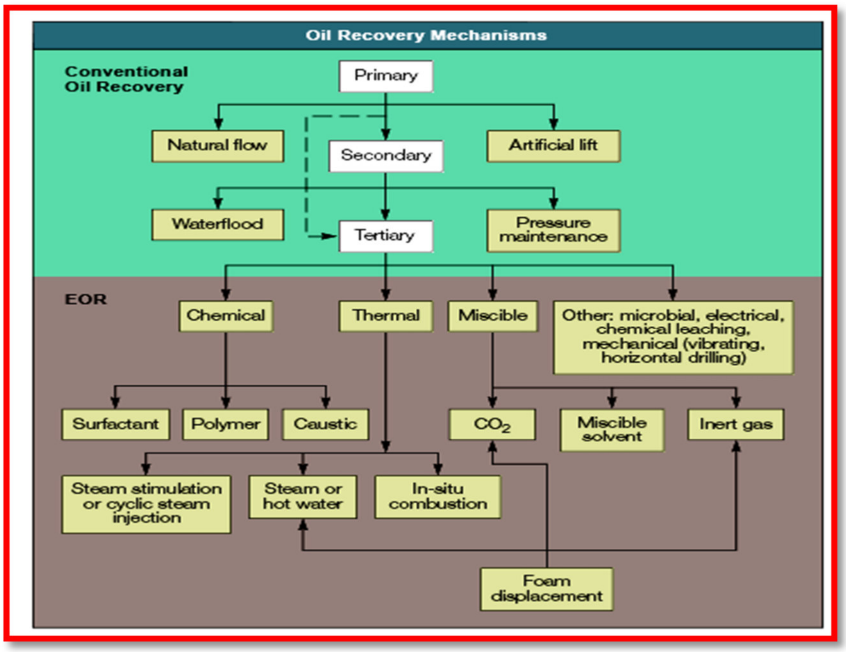

Figure Shows Oil Recovery Methods

❖ Screening criteria for different EOR methods are shown in the following table:

2- Screening of possible EOR Methods for A_{lm} Field:

Table (1) Shows summary of screening criteria for EOR Methods

	Oil Properties			Reservoir Characteristics					
EOR Method	**Gravity (°API)**	**Viscosity (cp)**	**Composition**	**Oil Saturation (%PV)**	**Formation Type**	**Net Thickness (ft)**	**Average Permeability (md)**	**Depth (ft)**	**Temperature (°F)**
Gas Injection Methods (Miscible)									
N_2 & Flue gas	>35	<0.4	High present of C1 to C7	>40	Sandstone or Carbonate	Thin unless dipping	NC	>6000	NC
HC	>23	<3	High present of C2 to C7	>30	Sandstone or Carbonate	Thin unless dipping	NC	>4000	NC
CO_2	>22	<10	High present of C5 to C12	>20	Sandstone or Carbonate	Wide range	NC	>2500	NC
Immiscible gasses	>12	<600	NC	>35	NC	NC if good vertical (K)	NC	>1800	NC
(Enhanced) Water flooding									
Micellar/ polymer, Alkaline	>20	<35	Light, Intermediate	>35	Sandstone preferred	NC	>10	<9000	<200
Polymer Flooding	>15	10 to 150	NC	>50	Sandstone preferred	NC	>10	<9000	<200
Thermal									
Combustion	10 to 27	<5000	Some asphaltic component	>50	High porosity sand/ sandstone	>10	>50	<11500	>100
Steam	8 to 25	<100000	NC	>40	High porosity sand/ sandstone	>20	>200	<5000	NC

NC = not critical
K = permeability

To determine the appropriate oil production methods and the flow regime of fluids in the formation, it is necessary to know the chemical and physical properties of oil, gas and water. That solves the important technical issues during the various production procedures; Alm field oil contains high percent of paraffin and very low percent of sulphar and ash.

The following table shows the average rock and fluid properties for A_{lm} field.

From previous technical comparative for each EOR methods: it seems likely that miscible CO_2 injection is main most favorable technique to be considered for A_{lm} field, Among the CO_2-EOR processes described previously, CO_2-WAG is strongly and technically recommended for A_{lm} field.

The Average rock and fluid properties for A_{lm} field

Area Concession	**A_{lm} field**		
History Production start-up	Dec. 1990		
Reservoir and Structure Formation Lithology Depth (m) Gross thickness (m) Net/Gross ratio (%) Porosity (%) Water saturation (%) Permeability (mD) OOWC (mss) Initial pressure (psi) Min. resev. Operat. Press. (psi) Temperature (°F)	 P_J Sandstone 2840 20-100 80 14.9 19 500-3000 2792 4650 3000 205	 De Sandstone 2790 20-40 21 9.3 42 10-100 2792 4650 3000 205	 Rm Carbonate/chert 2735 35 84 Fractures Unknown 0 in matrix 2792 4650 3000 205
Initial Fluid Properties Oil gravity (°API) Initial solution GOR (scf/stb) H_2S/CO_2 (vol.%) In-situ oil viscosity (cp) Oil formation volume factor (bbl/stb)	 34 400 ±100 0/1.6 0.77 1.16	 35.3 800±100 0/1.7 0.38 1.15	 31 350±100 0/0.5 0.98 1.08

3-Oil Recovery Factor by CO_2 for A_{lm} field:

The recovery factor by CO_2–EOR process is calculated as follows:

$$R = \frac{B_o}{S_{oi}.B_{oi}}\left(S_{orw} - S_{orm}\right)E_{vm}\left(\frac{E_m}{(E_{vm})}\right)$$

Where:

R ≡ Recovery factor by CO_2 process (%).

E_{vm} ≡ Volumetric sweep efficiency of the water flood (%).

E_m ≡ Sweep efficiency of CO_2 miscible displacement (%).

S_{orm} ≡ Residual oil saturation in zone swept by CO_2 (%).

S_{orw} ≡ Average oil saturation in the reservoir volume swept by the water flood (%).

S_{Oi} ≡ Oil saturated in the reservoir at discovery (%).

B_{Oi} ≡ Oil formation volume factor at initial pressure.

B_O ≡ Oil formation volume at the reservoir pressure, which exists when Np are produced, where:

Np ≡ ultimate oil recovery by primary and secondary methods (Stock-tank-barrels).

When substituting the given parameters values (for A_{LM} field) R will be:

R = 12.229%

This value lay between the expected value EOR recovery factor for WAG-CO_2 injection, which usually varies **between (5-15) %** , The recovery factor was considered **(R_f=12%)** for economical evaluation, then the predicted rate of recovered oil production according to WAG-CO_2-EOR process can be calculated as follows:

$R_{st} = R_f \times N$

N ≡ estimate initial oil in place (stocktank-barrels).

$R_{st} = 0.12 \times 265 \times 10^6 = 32$ MMbbl.

4-Volumes of Injected Materials: (CO_2, H_2O)

Injection rate / Project Life	CO_2 gas (MMcf/day)	Water (bbl/day)
10 years	46.500	23000
15 years	31.000	15525

5-Predicted Oil production Forecasts:

The following tables and figures show the oil production forecasts curves in case of:
(10, 15) years for the project life of A_{lm} field.

Table Shows Oil Production Forecasts Incase of (10) Years

Years	Oil Production (bbl/day)	Annual Production (MMSTB)	Cumulative Ann. Prod. (MMSTB)	Recovery Factor (%)
1	10000	3.4	3.4	1.283019
2	13500	4.59	7.99	3.015094
3	15000	5.1	13.09	4.939623
4	13500	4.59	17.68	6.671698
5	11052.87	3.757974	21.43797	8.089802
6	9049.321	3.076769	24.51474	9.250846
7	7408.957	2.519045	27.03379	10.20143
8	6065.941	2.06242	29.09621	10.9797
9	4966.372	1.688567	30.78478	11.6169
10	4066.122	1.382481	32.16726	12.13859

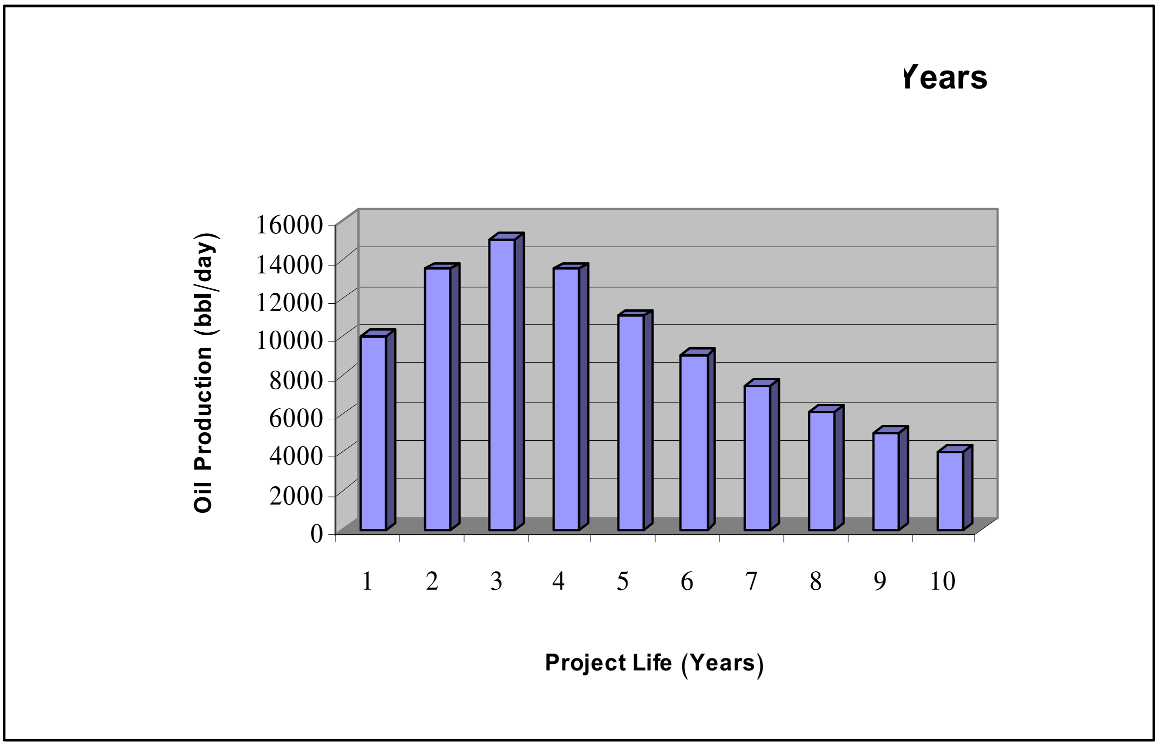

Figure Shows oil production forecast curve incase of (10) years

Table Shows Oil Production Forecasts Incase of (15) Years

Years	Oil Production (bbl/day)	Annual Production (MMSTB)	Cumulative Annu. Prod. (MMSTB)	Recovery Factor (%)
1	9000	3.06	3.06	1.1547
2	11500	3.91	6.97	2.6301
3	14000	4.76	11.73	4.4264
4	13152.36	4.4718	16.2018	6.1138
5	10430.35	3.5463	19.7481	7.4521
6	8271.686	2.8123	22.5605	8.5133
7	6559.779	2.2303	24.7908	9.3550
8	5202.168	1.7687	26.5595	10.0224
9	4125.527	1.4026	27.9622	10.5517
10	3271.709	1.1123	29.0746	10.9715
11	2594.596	0.8821	29.9567	11.3044
12	2057.619	0.6995	30.6563	11.5684
13	1631.774	0.5548	31.2111	11.7778
14	1294.062	0.4399	31.6511	11.9438
15	1026.243	0.3489	32.0000	12.0755

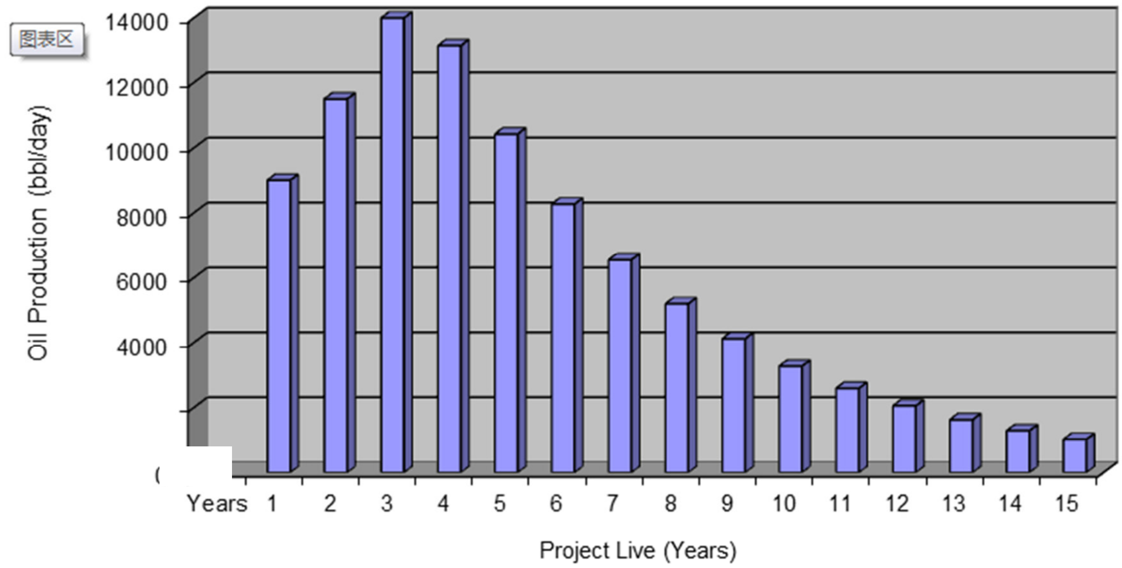

Figure (4-2) Shows Oil Production Forecast curve incase of (15) Years

6- The Sources of CO_2 and Total Costs per Mcf of CO_2 (US$) for A_{lm} :

The greatest consumer of carbon dioxide (accounting for over 60% of total consumption) is enhanced oil recovery process.

CO_2 sources are shown in the following table.

The main sources of CO_2 in Syria are: Ammonia units, thermal stations, Fermentation, but the most probable source economically is natural gas fields as example (Gbiseh fields) which contain about 10% CO_2, and the distance between the Deir ez-Zour and Gbiseh gas field is about 150 Km, that decreases the cost of CO_2 transportation.

Total costs of CO_2 EOR can be divided into costs for: 1) capture, 2) compression, 3) transport, and 4) injection.

Table Shows the Sources of CO_2

The Sources	***The Concentration***
Natural sources from mineral origin	More than 90% (volumetric)
Natural gas or connate gas	Up to about 20% (must be purified)
Ammonia units	More than 90%
Thermal stations (with natural gas) smoke	Less than 10% (must be purified)
Thermal stations (with fuel) smoke	Less than 15% (must be purified)
Ethylene oxide units	More than 90%
Waste products smoke	3-15% (must be purified)
Boilers smoke	30% (must be purified)
Fermentations	More than 90%

Table Shows Total Costs per Mcf of CO_2 (US$) for A_{LM}

Pipeline capacity (MMcf/day)	Distance (miles)	Capture cost (US$/Mcf)	Transp. cost (US$/Mcf)	Comp. cost (US$/Mcf)	Extract from manuf.	Gather from manuf.	Full cost for natural	Full cost for manuf.
50	100	0.22	0.233	0.24	0.9	0.9	0.693	0.273

7- Base Case Economic Parameters for A_{lm} Field

Table Shows Estimated Costs for A_{lm} Field

No.	Process	Cost estimation	Units
1	Oil price	40	US$
2	CO_2 injection rate	46.5 (10years)	MMcf/day
3	Projection duration	2 scenarios (10+15)	Years
4	Water injection rate	15.5 (10years)	Bbl/day
5	Recovery factor	12 (OOIP)	%
6	*I.o.r.EOR-CO_2-WAG	32	MMbbl
7	CO_2/oil required rate	5	Mscf/STB
8	Engineering costs	25/Equipment cost	%
9	CO_2 capture cost (NG)*	0.22	US$/Mcf
10	CO_2 compression cost (NG)	0.24	US$/Mcf
11	CO_2 Trans. cost	0.233	US$/Mcf
12	CO_2 injection cost	0.22	US$/Mcf
13	Pipeline cost (150Km)	19.44,capex	MMUS$
14	O&M *	0.47	MMUS$
15	Operational costs	5 (Equipment cost)	%
16	Energy compressor	0.032	US$/Kwh
17	New injection well cost	5	MMUS$
18	Produced gas processing cost(recycle)	60 (compression& Injection rate)	%
19	Electrical Energy Cost (CO_2-WAG)	5	Hp/Bopd
20	Storage ratio	50	%

*I.o.r = Incremental Oil Rate According to EOR-CO2-WAG.
*NG = Natural Gas.
*O&M = Operational and Maintenance.

The following diagram shows cumulative production, predicted, and remained oil percents for A_{lm} field after EOR-CO_2-WAG.

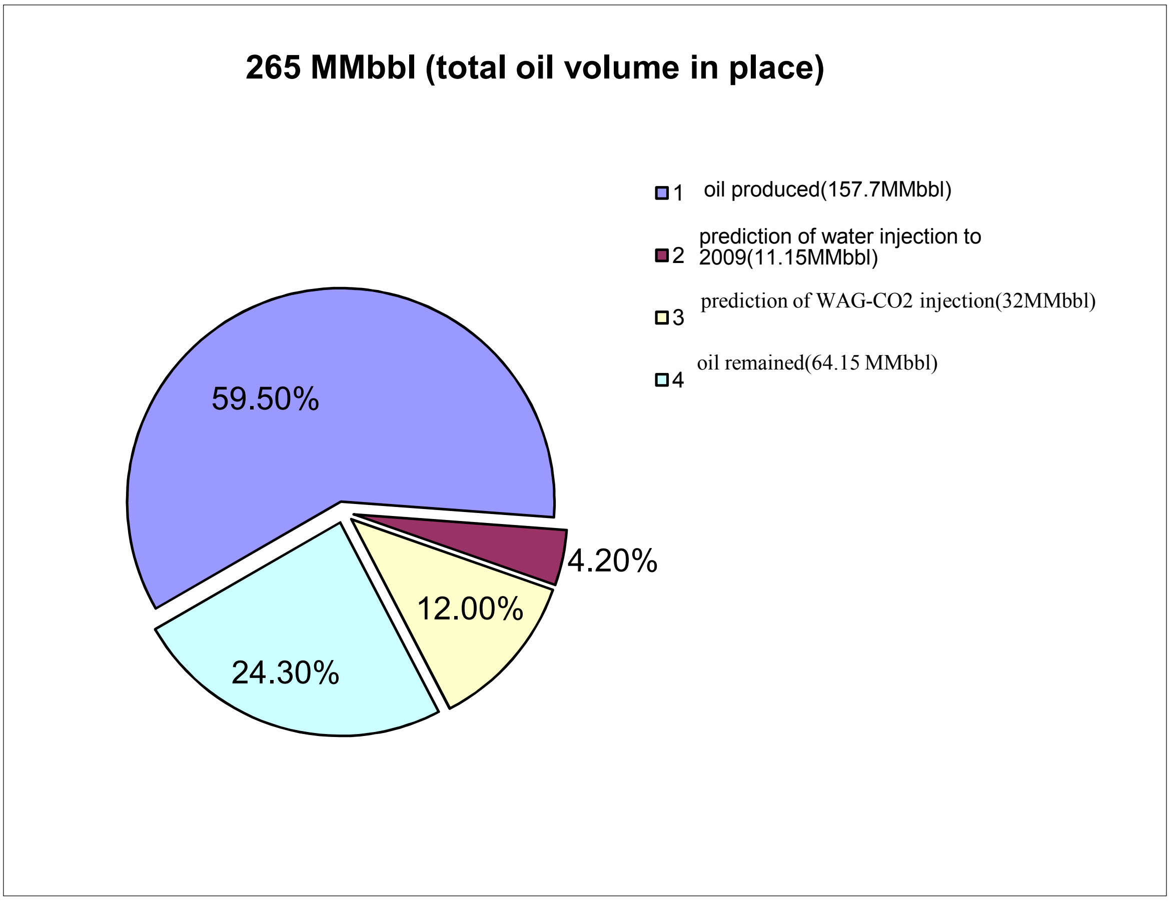

Figure shows cumulative production, predicted, and remained oil percents for A_{lm} field after EOR-CO_2-WAG.

Conclusions

- CO_2-WAG seems most likely favorite enhanced oil Recovery (EOR) technique for A_{lm} field.
- Prediction of CO_2-WAG injection performance in A_{lm} Field shows that an oil recovery factor of 12% OOIP can be realized.
- Natural CO_2 is most feasible for injection in A_{lm} field with capture cost of US$ 0.2/Mcf.
- Transportation via pipelines is most technically and economically suitable.
- The cost of moving CO_2 along the complete value chain (capture, compression, transportation, injection) can approximately be US$0.7/Mcf in case of natural gas source, and US$ 2.28/Mcf in case of manufactured source.
- For Alm field 1-ton of injected CO_2 can produce 3.87 STB of oil.
- Maximum of 1-horizontal and 4 vertical infill wells can be drilled; the location of these wells should be selected based on more detail reservoir study.

Recommendations

- Conduct more detail study using compositional simulation to predict the reservoir performance based on sector model.
- For applying this technique in A_{lm} field a pilot project has to be designed until reaching to full-scale project.
- With the high oil prices nowadays (greater than 60US$/bbl) CO_2-EOR projects will be need government and big specialized companies supports
- Because of the facilities are not designed or high levels of corrosion resistance, protection techniques should be taken such as: inhibitors, some parts of the system can be replaced.

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