CO\textsubscript{2} use could boost Egypt’s Western Desert oil recovery

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The main objective of this study was to develop a strategy that maximizes use of CO\textsubscript{2} emissions from the Egyptian Western Desert. The study evaluates ways to capture these emissions for enhanced oil recovery (EOR) and assesses the applicability of CO\textsubscript{2} injection in candidate fields.

Egypt has a single successful thermal EOR project, but no operator has tried even a pilot to test the feasibility and economics of CO\textsubscript{2} miscible injection, which is the most widely applied EOR process worldwide (OGJ, Oct. 1, 2012, p. 84; Apr. 2, 2012, p. 57).\textsuperscript{1}

The authors of this article, members of the Petroleum and Petrochemical Consultation Group, are trying to push a CO\textsubscript{2} pilot in Egypt. They have discussed the concept with the last two ministers of petroleum and chairmen of Egyptian General Petro-

Concept

The first activity in this project was to screen 37 reservoirs to identify those most suitable for CO\textsubscript{2} injection. The screening was carried out with specialized software (EOR Graphical User Interface-EORgui). Results of the screening indicated five reservoirs as candidates. These lie in three Badr El-Din Petroleum Co. (Bapetco) oil fields: the Abu Roash G formation in Badr El Din (BED) 3C9 field, the Abu Roash C formation in BED 3-6/3-11 field, and Abu Roash C, Kharita, and Bahariya formations in BED 1 field.

The results indicate 76.2 billion std. cu ft (bscf) of CO\textsubscript{2} to be required for injection. Injection of CO\textsubscript{2} is expected to increase the incremental oil recovery by 7.62 million stock-tank bbl (stb), or 10% of the original oil in place (OIP).

The study clarifies that the main sources of CO\textsubscript{2} in the Western Desert are gas processing plants. Currently, 51.2 MScf/d of CO\textsubscript{2}-rich gas (about 70% CO\textsubscript{2}) can be recovered as byproduct from four main gas processing plants: Obayed, El Salam, Tarek, and El Qasr.

The CO\textsubscript{2}-rich gas streams can be gathered from the four plants to a central point in the El Salam area, then transported via 130-mile, 16-in. pipe-
line to Abu Sennan field to be stored in order to fulfill the EOR project's needs (Fig. 1).

This project can contribute to the improvement of Egyptian security of supply by increasing oil production and assisting in the reduction of greenhouse emissions.

**Candidate oil reservoirs**

Egypt's Western Desert is one of the country's largest oil producing areas. It is being developed with new discoveries that include some of the largest producing oil and gas fields in Egypt.

The main exploration and production operating companies in the Western Desert are Khaldi Petroleum Co., a joint venture of Apache Corp. and Egyptian General Petroleum Corp.; Badr El Din Petroleum Co., a joint venture between Shell Egypt NV and EGFC, General Petroleum Co. (GPC) of Egypt; Agiba Petroleum Co., a joint venture between IEOC BV and EGFC; and Qarun Petroleum Co., another Apache-EGFC JV.

Recent production rates from the Western Desert are about 305,000 b/d of oil and 1.4 bscfd of gas.

The main Western Desert producing formations are Abu Roash C, Abu Roash D, and Bahariya. Abu Roash C and Bahariya are mainly sandstone, and Abu Roash D is mainly limestone.

In the current work, 24 oil fields containing 37 depleted reservoirs were selected for study. The depths of the studied reservoirs range between 900 m and 3,400 m. The initial reservoir pressure range is 1,750-5,000 psi; however, the current reservoir pressure range is 1,250-3,500 psi. Reservoir temperatures are 92-127°F. The oil is 33-40° gravity. Table 1 summarizes the main data of the selected oil reservoirs.2

Screening of the fields was carried out with specialized software (EOR Graphical User Interface – EORgui). Through the use of the EORgui software, the oil fields and reservoirs were screened and the potential of applying CO2 techniques was identified.

Table 1 presents the results of the preliminary screening for the studied reservoirs. The data indicate that the most appropriate EOR methods for the studied oil fields appear to be CO2 injection, immiscible gas injection, and alkali-surfactant-polymer/polymer-surfactant injection.

Based on the history of successful EOR project results, CO2 miscible flooding seems to be the most appropriate method, and results indicate that the five reservoirs in the three fields are the most suitable for applying it (these res-
**ADDITIONAL OIL RECOVERY, CO₂ REQUIREMENTS**

<table>
<thead>
<tr>
<th>Field</th>
<th>Reservoir</th>
<th>OOIP million bbl</th>
<th>Required CO₂ bscf</th>
<th>Additional oil recovery by CO₂, EOR, million bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>BED 3C9</td>
<td>A R &quot;C&quot;</td>
<td>9</td>
<td>9</td>
<td>0.9</td>
</tr>
<tr>
<td>BED 3-63-11</td>
<td>A R &quot;C&quot;</td>
<td>3.5</td>
<td>3.5</td>
<td>0.35</td>
</tr>
<tr>
<td>BED 1</td>
<td>A R &quot;C&quot;</td>
<td>15.8</td>
<td>15.8</td>
<td>1.58</td>
</tr>
<tr>
<td>BED 1</td>
<td>Khanta</td>
<td>14.9</td>
<td>14.9</td>
<td>1.49</td>
</tr>
<tr>
<td>BED 1</td>
<td>Baharya</td>
<td>33</td>
<td>33</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**CO₂ sources, pipelines, storage**

Table 3 shows the main characteristics of the gas processing plants that represent the main source of CO₂ in the Western Desert. Together the plants discharge about 51.2 MScfd of CO₂-rich gas (70% CO₂).

The study is extended to determine the optimum design considerations of the CO₂ network that connects different CO₂ source plants to the sites of storage and utilization.

The available CO₂ is initially planned to be gathered in the El Salam area. Then it is to be transported to Abu Sennan field for storage in order to fulfill the needs of the CO₂ EOR projects (Fig. 1). Table 4 presents the results of the hydraulic calculations for the pipeline network.

The pipelines would be protected against corrosion by insulating joints, internal coating, and corrosion inhibitors. The doses and the type of corrosion inhibitors should be identified by a chemical treatment company during the detailed engineering phase.

The designs and hydraulic calculations are to be carried out with several constraints. These include maintaining reasonable velocity in the pipelines, maintaining reasonable pressure drop across the pipelines, avoiding hydrate formation, and optimizing pipeline size to reduce project cost.

The shortest possible route would be followed to minimize the pipeline length, compression requirements, and the number of crossings, taking into account construction accessibility.

The pipelines are to be buried for security, piggable, and fitted with external coating and cathodic protection. Tie-in points are recommended every 20 km to accommodate future expansion from other sources.

The ability to store CO₂ in a depleted reservoir in the Western Desert is also studied. The general requirements for the geological storage of CO₂ include the following:

- Storage capacity is large enough.
- The storage reservoir has sealing layers top and bottom.
- The reservoir has adequate geological characteristics such as porosity, thickness, and permeability.

The study indicates that Abu Sennan field, which belongs to GPC, is the best option for CO₂ storage in the Western Desert. The field includes three depleted reservoirs: Khoman, Abu Roash B, and Baharya. Table 5 presents the main characteristics of the three Abu Sennan reservoirs.
Depleted Reservoirs at Abu Sennan Field*

<table>
<thead>
<tr>
<th>Reservoir/formation</th>
<th>Well</th>
<th>g fraction</th>
<th>H, m</th>
<th>P, psi</th>
<th>Pw, psi</th>
<th>R, bcf</th>
<th>Qcum, bcf</th>
<th>RR, bcf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khoman Depth, 1,300 m</td>
<td>GPT #3</td>
<td>0.24</td>
<td>162</td>
<td>1,700</td>
<td>400</td>
<td>72</td>
<td>61</td>
<td>11</td>
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<td></td>
<td>GPT #5</td>
<td>0.23</td>
<td>134</td>
<td></td>
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<tr>
<td></td>
<td>GPT #9</td>
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<td>105</td>
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<tr>
<td></td>
<td>GPT #11</td>
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<tr>
<td></td>
<td>GPT #14</td>
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<td>114</td>
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<td></td>
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<tr>
<td></td>
<td>GPT #21</td>
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<td>96</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>GPT #3</td>
<td>0.09</td>
<td>16</td>
<td>2,022</td>
<td>850</td>
<td>11.5</td>
<td>6</td>
<td>5.5</td>
</tr>
<tr>
<td>Abu Roassh Depth, 1,500 m</td>
<td>GPT #5</td>
<td>0.09</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>GPT #16</td>
<td>0.12</td>
<td>16</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>GPT #21</td>
<td>0.09</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baharia Depth, 1,950 m</td>
<td>GPT #17</td>
<td>0.2</td>
<td>14</td>
<td>2,850</td>
<td>100</td>
<td>20</td>
<td>14</td>
<td>6</td>
</tr>
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<td></td>
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<td>0.22</td>
<td>20</td>
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</tr>
<tr>
<td></td>
<td>GPT #21</td>
<td>0.21</td>
<td>17</td>
<td></td>
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</tr>
</tbody>
</table>

*φ: porosity; H: gross thickness; P: initial pressure; Pw: current pressure; R: reserve; Qcum: cumulative production; RR: remaining reserve.

It consists of a white chalky limestone occasionally fractured with calcite infilling with micritic and pyrite.

Technical considerations, recommendations

The most critical parameter with respect to miscible CO₂ flooding is the minimum miscibility pressure (MMP). The MMP is required so that CO₂ becomes fully miscible with oil.

The MMP depends on the composition of crude oil, the purity of CO₂, and reservoir pressure and temperature. Hence, a miscible CO₂-displacement technique can only be implemented when CO₂ can be injected at a pressure higher
Technology

than the MMP, which in turn must be lower than the reservoir fracture pressure.

Preferably, the injection pressure at the start of a CO₂ flood should be at least 14 bar above MMP to achieve miscibility of CO₂ and reservoir oil. This means that the ratio between reservoir pressure and minimum miscible pressure (P/MMP) normally should be greater than 1.0, but CO₂ flood EOR is still possible for P/MMP greater than 0.9.²

Because of the uncertainties of both calculation of MMP and measured pressure data, reservoirs with P/MMP greater than 0.9 are regarded as suitable for CO₂ floods by this screening if the reservoir pressure is lower than the original reservoir pressure at the start of CO₂ injection. The MMP can today be measured experimentally or predicted with empirical equations and thermodynamic modeling with good accuracy (OGJ, Jan. 7, 2013, p. 74).

The utilization factors of solvent range between 6 and 10 Mcf/incremental barrel of oil recovered.⁶,⁷

Data from 10 miscible displacement projects in the Texas-New Mexico Permian basin indicate that the net injection of CO₂ into an oil field (i.e. the difference between total CO₂ injection and the recycled CO₂) is on average 164 cu m/bbl (6,000 cu ft) of incremental oil (about equivalent to 330 kg/bbl). This value has shown to vary between 270 kg/bbl in Rocky Mountain projects to 400 kg/bbl in the US Midwest.

On average, oil recovery has been 10.9% of original oil in place in the Permian basin.¹ The net volume of CO₂ injected is 10-45% of the volume occupied by the hydrocarbons in the reservoir.⁹

Because of differences in density and viscosity between the injected fluid and the reservoir fluids, the miscible process often suffers from poor mobility. Viscous fingering and gravity override frequently occur. The simultaneous injection of a miscible agent and brine is suggested in order to take advantage of the high microscopic displacement efficiency of the miscible process and the high macroscopic displacement efficiency of a waterflood.

Several variations of the simultaneous injection scheme are suggested. They typically involve the injection of a miscible agent followed by brine or the alternating of miscible agent-brine injection. The latter variation has been named the WAG (water alternating gas) process and has become the most popular.

A balance between amounts of injected water and gas must be achieved. Too much gas will lead to viscous fingering and gravity override of the gas, whereas too much water could lead to the trapping of reservoir oil by the water. The addition of foam-generating substances to the brine phase has been suggested as a way to aid in reducing the mobility of the gas phase.

The highest oil recovery efficiencies are associated with the implementation of the tapered WAG injection technique where the ratio of injected water to CO₂ changes with time, starting with larger CO₂ slugs that are progressively reduced in size.¹⁰

The main issues in implementing CO₂ EOR in Egypt are:

- Corrosion of some infrastructure already in place that was not designed for CO₂ use when initially installed.
- Increased capital expenses for modifying existing infrastructure and purchasing and installing additional equipment such as CO₂ compressors.
- Capital and operating expenses for the construction and operation of a CO₂ pipeline network.
- Uncertainty surrounding the legal framework for CO₂ underground storage.
- Need for coordination and agreement between CO₂ source companies and the oil producers for the execution of the EOR projects.

References

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