Evaluation of CO_2 flooding on the Grane Field.

Peder Skotner, Norsk Hydro

Introduction

CO_2 is usually injected with the purpose to achieve a fully miscible displacement of oil. In this respect, the planned Grane CO_2 flood is atypical because the Grane oil is heavy and not miscible with CO_2.

However, due to favorable reservoir conditions, gravity stable displacement and large swelling effects, the recovery achieved by CO_2 injection is far superior to water injection and similar to natural gas injection.

Reservoir description

The Grane Field is located about 160km west of Karmøy in block 25/11, licenses PL169 and PL001. The water depth is 129m. The reservoir consists of a highly permeable and highly homogeneous turbidite sandstone belonging to the Heimdal formation. The depth to top reservoir is about 1680 mMSL and the oil/water contact is located at about 1765 mMSL. The area of the oil zone is about 25.5 km^2, with an average 31m thick oil column. The reservoir is mostly underlain by water and has an assumed weak link to the overall Frigg/Heimdal/Grane tertiary aquifer system. The Grane structure is expected to contain 191 MSm^3 of undersaturated 19 degree API crude. The main data base is 3D seismic, 3 vertical appraisal wells (-15, -18, -21S), and a horizontal sidetrack (-21 AT2) where an extended well test was performed summer 1996. The oil is viscous, 10-12 cP at initial reservoir pressure and reservoir temperature. Reservoir properties are summarized in table 1.

Table 1. *Grane reservoir properties*

Crest	*1680 mMSL*
OWC	*1765 mMSL*
A	*25.5 km^2*
H_{oil}	*31m*
STOIIP	*191 MSm^3*
K	*10D*
N/G	*0.97*
ϕ	*33%*
B_{oi}	*1.065 Rm^3/Sm^3*
P_i	*176 bar*
P_b	*50-60 bar*
T_i	*76 C*
GOR	*14-18 Sm^3/Sm^3*
μ_o	*10-12 cP*

The Field is in a late planning phase, with PDO submittal summer 1999 and estimated production start early 2003. Estimated oil reserves is 80 MSm3 – 120 MSm3.

The planned development is based on a fixed production and living quarters platform (PQ) with a bridge connection to a drilling platform (D). The reservoir will be drained by a large number of long reach horizontal producers drilled from the D platform. Long producing sections in the reservoir are necessary to reduce coning. Produced water and gas will be reinjected. Oil is planned to be exported via pipeline to Sture. In case of CO_2 injection, the CO_2 will be supplied by a planned HydroPower plant on Karmøy.

Figure 1 gives an illustration of the Grane reservoir and well locations.

CO_2 - Discussion of principal recovery mechanisms.

The original Grane oil is dead and thus not miscible with either CO_2 or natural gas. At reservoir conditions, CO_2 will be supercritical, "gaslike" with respect to viscosity (0.043 cP), and more "liquidlike" with respect to density (540 kg/Rm^3). For comparison, a fairly dry gas injected will have a density at reservoir conditions of 120 kg/Rm^3. When mixed with small amounts (5-10%) of reinjected solution gas, the density may be reduced by 100 kg/Rm^3.

Figure 2 illustrates the main recovery mechanisms. A discussion of these mechanisms for Grane follows.

Gravity stable displacement. Gas or CO_2 is injected at the crest and oil is produced by long horizontal producers located 9m or more above the OWC. The recovery efficiency is dominated by CO_2 and water coning. Gravity drainage behind the CO_2 front and endpoint mobility ratio at final "gas out" will also have some effect. Residual oil saturation after CO_2/gas flooding may be as low as 5% compared to 15% for water flooding.

Reservoir simulation currently show that natural gas injection is the most gravity stable, CO_2 injection is also gravity stable, while water injection experiences some breakdown of gravity stability due to excessive coning. This is due to very low density difference between water and oil (1020 kg/Rm^3 – 890 kg/Rm^3 = 130 kg/Rm^3).

Swollen oil coning. PVT experiments show that CO_2 dissolves in the oil and increases its volume 16% and decreases its viscosity from 10 cP to 2 cP. Because the displacement is downward gravity stable, the entire reservoir area will be contacted by CO_2. Horizontal displacement, with a mobility ratio of about 250 between injected CO_2 and original oil, would by contrast experience severe gravity tonguing, leaving most of the original oil behind uncontacted. At the interfase between CO_2 and original oil, a zone of swollen oil develops. This swollen oil cones through the more viscous original oil into the producers. The swollen oil will have a density similar to the original oil and there is no buoyancy force to retard the swollen oil cone. The swollen oil coning is very characteristic and was first observed in the full field simulation model and later reproduced in a finegridded cross-section model. Water coning is sensitive to oil viscosity, thus the production of swollen oil reduces water coning. The creation of swollen oil is limited by the very slow downward displacement velocity, about 1m/year. Reservoir simulation show that introduction of horizontal barriers, calcites, slump surfaces etc. stimulates oil swelling by introducing larger displacement velocities in the reservoir, mainly in the horizontal direction "around" these barriers. The positive effect on swelling can be explained by the fact that horizontal displacement has a more diffuse, unstable character, as opposed to the more "pistonlike" character of vertical displacement.

Reservoir simulation on Grane currently show that swollen oil coning is favorable for CO_2 and somewhat less favorable for natural gas.

Vaporization. This is the opposite effect of swelling, whereby the light components of the oil is dissolved in the CO_2. This process will take place behind the swollen oil zone in the presence of free CO_2, and will also to some extent interfere with the swelling process. The effect is negative, because the effective swollen or equilibrium oil viscosity will be higher. However, mixing CO_2 with small amounts (5-10%) of hydrocarbon gas will reduce the vaporization. Also on the positive side, the vaporization will strip some oil components behind the front and bring these to the surface.

Current simulation results show the vaporization effect to be somewhat negative for CO_2 and neutral for natural gas injection.

Conclusion

An immiscible CO2 flood on the Grane field has been evaluated.

The main reservoir processes identified are

- Gravity stable displacement
- Swollen oil coning
- Vaporization

The recovery achieved by CO_2 injection is far superior to water injection and similar to natural gas injection.

This may also be the case for some of the new tertiary oil discoveries being made, with characteristically high permeability and high oil viscosity as on Grane.

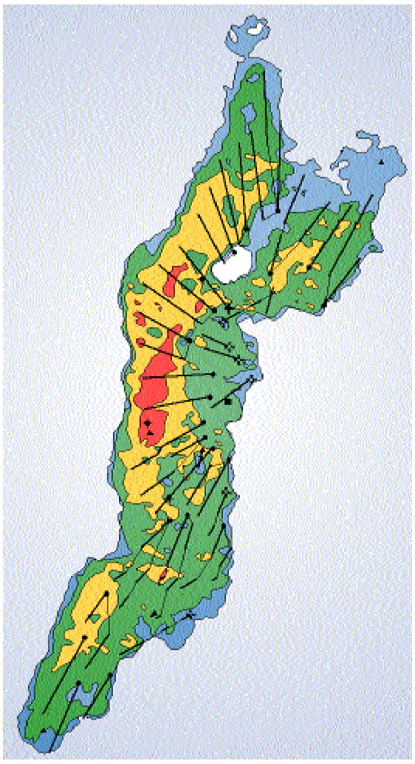

Figure 1. Grane reservoir with well locations.

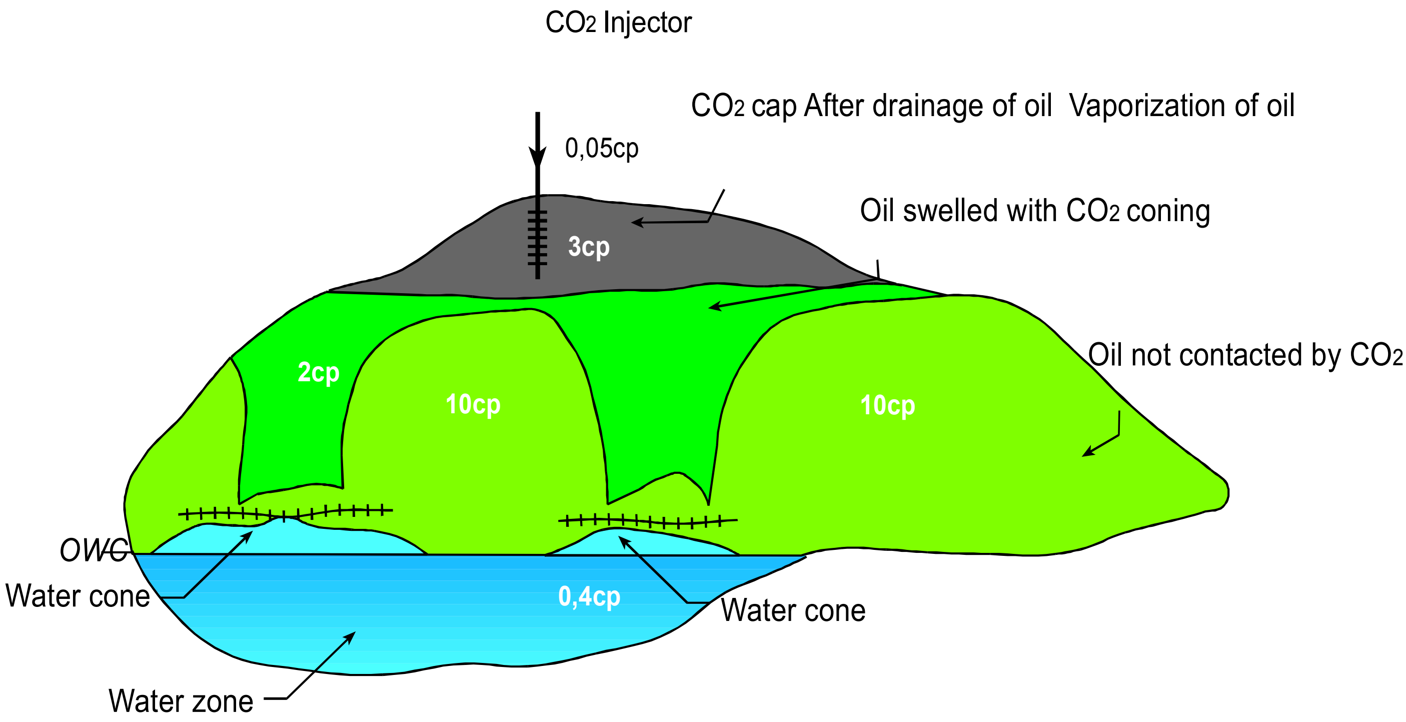

Figure 2. CO2 – Main recovery mechanisms