Ekofisk Field Enhanced Recovery

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Ekofisk Field, discovered in late 1969, was the first commercial discovery in the Norwegian Sector of the North Sea. The field has produced some 856 million barrels of oil and 2.6 trillion standard cubic feet of gas through 1988. Almost all of this has been primary production with solution gas drive and compaction playing major roles.

In June of 1986, the 2/4 K Waterflood Platform was installed at Ekofisk to enhance the recovery from the Tor Formation. The platform, weighing 38 000 tons, has slots for 30 injection wells and is equipped to inject 375 000 barrels of water per day. The platform was installed on the basis of results of laboratory imbibition tests and the Tor Formation Waterflood Pilot conducted from April 1981 to July 1984. These results indicated spontaneous imbibition of 48% could be expected in the Tor Formation. Simply stated, this meant that if seawater were introduced to the Tor Formation fracture system, it would enter the matrix, without benefit of a pressure differential, and displace, on average, hydrocarbons from 48% of the pore volume. Water injection was initiated in November 1987.

Laboratory tests on the Lower Ekofisk chalk indicate that spontaneous imbibition values are in the 25% range, but considerably greater changes in water saturation are achieved by viscous displacement with relatively small pressure differentials. The Lower Ekofisk Waterflood Pilot was initiated in July 1986 to determine whether sufficient water saturation changes could be achieved in the field, through a combination of imbibition and viscous displacement, to make waterflooding the Lower Ekofisk Formation commercial. The results of the pilot are positive and the expansion of the waterflood to the Lower Ekofisk as well as the south is in progress. Innovative modifications of existing platforms are being made to minimize the cost of project implementation.

Nitrogen injection appears to be an attractive method for displacing hydrocarbons, primarily natural gas, from the Upper Ekofisk Formation. A thorough evaluation is almost complete and a decision concerning nitrogen injection is anticipated by November 1989.

INTRODUCTION

The Ekofisk Field, located in the Central Graben in the Norwegian sector of the North Sea, originally contained more than 8 billion barrels of oil equivalents. Initially, only about 20% was thought to be recoverable through primary depletion. Reservoir compaction, which was discovered in late 1984, increased primary recovery estimates to 24%. The challenge that the Phillips Norway Group has faced and continues to face is how economically to enhance recovery from the fractured chalk reservoirs located in the middle of the hostile North Sea.

Early laboratory testing and a field waterflood pilot resulted in the decision to waterflood the northern two-thirds of the Tor Formation. A second waterflood pilot was established to determine the feasibility of waterflood- ing the Lower Ekofisk Formation. Positive results coupled with innovative concepts for platform modifications to accommodate additional producing wells led to expansion of the waterflood to the Lower Ekofisk Formation and to the southern portion of the field.

Nitrogen injection can improve recovery by molecular diffusion into the matrix, vaporization of solution gas from residual oil, and overall pressure maintenance. A decision on the project is expected in November 1989.

RESERVOIR DESCRIPTION

The Ekofisk Field is an elongated anticline with the major axis running N–S (Fig. 1) and covers approximately 12 000 acres (4860/ha).

Ekofisk Formation

The upper producing horizon of Ekofisk Field is the Ekofisk Formation of Danian age in the Paleocene Period. It is located at a depth of about 9600 ft and ranges in thickness from 330–500 ft. The natural fractures in this chalk reservoir enhance matrix permeability values, typically 1–5–mD, to an effective permeability approaching 100 mD. Porosity ranges from 30% to 48%.

Tight Zone

The Tight Zone is the bottom portion of the Ekofisk Formation and forms an impermeable barrier between the
Ekofisk and Tor Formations. It is approximately 50 ft thick and has a porosity in the 10–20% range. The Tight Zone has been faulted out in two areas of the field forming “windows” between the two reservoirs (Fig. 2).

**Tor Formation**

The lower reservoir is the Tor Formation of Maastrichtian age in the Cretaceous period. It is also a fractured chalk reservoir ranging in thickness from 250 to 500 ft. Its porosity ranges from 30% to 40% + and effective permeability reaches 100 mD.

**Mineralogy**

The mineralogy of both formations is similar, being a fine-grained limestone composed of skeletal debris of coccolithophorides, a pelagic unicellular alga. The calcareous exoskeletons of these algae are called coccospheres, comprised of wheel-shaped coccoliths. The great majority of the matrix is composed of the calcite crystal component of a coccolith called a coccolith platelet. Whole coccoliths are relatively common but preserved coccospheres are rare (Fig. 3).

Chalk in the Lower Ekofisk and Tor Formations is relatively clean with generally less than 5% non-carbonate impurities. The Upper Ekofisk, however, contains as much as 20% impurities, mainly silica.

**Figure 1.** Structure map of Ekofisk Field, Top Tor Formation.

**Figure 2.** “Windows” of communication between the Ekofisk and Tor Formations.

**Figure 3.** SEM micrograph of a preserved “cocosphere”.