ABSTRACT

According to the current prognosis the total oil production, from existing fields and from fields with sanctioned development on the Norwegian Continental Shelf (NCS), will decline within a few years. In ten years, the oil production is expected to drop to one third of the present level of 180 MSm³/year (1.1 billion bbl/year).

A workgroup has been investigating the possibility of maintaining the production at present level beyond year 2005. The study revealed two major potential contributors in this respect. One is expected discoveries of new fields with sufficient economical production potential. The other, which is anticipated to dominate in the near term, is IOR from fields presently in production. This paper will focus on the latter.

The methodology established to evaluate the IOR-potential on the NCS is presented, including a new IOR-definition.

The IOR-potential was found to be substantial, with robust economy. The high estimate is more than 700 MSm³ (4.4 bill. bbls), which is comparable with the total recoverable reserves in the Statfjord field.

Statoil is presently detailing an IOR-implementation process, including technology development, organizational issues and cooperation with partners, to ensure an economical utilization of the IOR-potential.

This paper outlines the key IOR-techniques. It is demonstrated that a few major techniques dominates.

INTRODUCTION

The total oil production rate on the NCS has steadily increased since production commenced in 1971. However, several of the giant oil fields which have been set on production in this period as Ekofisk (1971), Statfjord (1979), Gullfaks (1986) and Oseberg (1988), are in the decline or late plateau phase. Although several new fields have been set on production over the last few years, they can not compensate for the expected decline of the giants. Hence, the production prognosis (as of 1.1.96) for the NCS shows significant decline from the turn of the century (see Figure 1).

New discoveries can not compensate for the expected decline. If huge oil accumulations are found, they will probably not be set on stream in due time. Hence, more focus has been put on the potential contribution from increased oil recovery from existing fields.

Due to improved reservoir knowledge, improved drilling and completion technology, and more efficient utilization of water and gas injection, the expected oil recovery factor for the fields on production on the NCS has increased with more than five percent points during the last five years. The corresponding number for Statoil operated fields is eight percent points, as illustrated in Figure 2.

Despite the already relatively high oil recovery factors, in average 39%, it is anticipated that the ultimate economical recovery factor is even higher, and that increased focus on IOR may turn out to be a key element in the effort to maintain the present production level. In order to succeed, it is important to focus on improving both volumetric and microscopic sweep efficiency.
A large fraction of the oil in place on the NCS is light oil, found in medium to high permeability reservoirs. The well spacing in these offshore reservoirs is normally very low. Hence gravity plays an important role in the displacement process, and experience indicates that combination of water and gas injection will, for a number of low dip reservoirs, improve the vertical sweep efficiency compared with single phase water or gas injection. There are, however, still large challenges to be met in identifying and recovering oil bypassed either by gravitational influence or due to the heterogeneous nature of most of the NCS reservoirs.

A key element in the process of converging towards the optimum IOR-strategy is focus on technology development. This has been a key issue for the last decade through a number of Norwegian governmental and industry funded research programs. Although it is difficult to quantify, there is no doubt that the significant attention IOR has gained through these programs has contributed to increase oil reserves.

**METHODOLOGY**

Important elements of the methodology used to estimate the IOR potential on the Norwegian Continental Shelf are outlined, including a new IOR definition, guidelines how to organize the project/human resources involved, and a project evaluation procedure.

**New IOR definition**

A large variation in definitions of the overlapping terms Reservoir Management, Improved Oil Recovery (IOR) and Enhanced Oil Recovery (EOR) are commonly used. Hence, no generally accepted definition of IOR exists. Most definitions found in the literature focus on volumes, and comprehensive studies are often performed before project economy are calculated. Such working procedure is both time and resource consuming. In order to speed up the process and make the IOR-projects more decision-oriented it was necessary to introduce a new IOR-definition based on economy. Statoil now defines IOR-projects as:

'Profitable projects that increases or accelerates production, by additional investments or innovative exploitation strategy'.

According to this definition most activities beyond proven Plan of Development and Operations (PDO), which improve field economy, are included as IOR-projects. Hence IOR-activities are related both to reservoir as well as surface related operations. It should be noted that the economy of IOR-projects will depend both on oil prices and the frame conditions set by the authorities.

**Human resources - project organization**

IOR is a multidisciplinary task, and it is a key element to bring together people with different background, enabling the most efficient evaluation of the potential IOR-projects and effectively utilize the human resources. Consequently, a core team (the IOR-team) comprising high-qualified members from geophysics & geology, reservoir technology, production technology, drilling & completion, process, operations and R&D was established (see Figure 3). Other disciplines are included when required. The core team typically consists of 6-8 persons, depending on the challenges. The main purpose of the IOR-team is to stimulate people within the assets, transfer experience between assets, and finally secure necessary drive on implementation of proven IOR- schemes. The team is also connected to a network including management, assets, technical advisors, research institutes and service industry.

To obtain proper evaluation of the total IOR-potential, it was of vital importance to involve people with operational experience. Therefore, each asset was responsible for preparing its own IOR-scheme. For specialized technical studies the head-office was involved.

**Project evaluation**

In order to ensure systematic evaluation of the IOR-potential, a standard concept with objectives and evaluation methodology was worked out (see Figure 4). The concept includes a simple evaluation procedure, an internal resource classification system and a summary spread sheet including a check list of more than 60 available IOR methods. Each IOR-scheme should include IOR-volumes and corresponding production profiles, investments and operational costs, net present value (NPV), internal rate of return (IRR) and evaluation of risk.
For each asset the main elements in the evaluation procedure are:

- identify bottlenecks for increasing the reserves,
- identify needs for technology development and pilots, and the time available for qualification,
- consider IOR over the entire field life,
- calculate NPV and IRR of the IOR projects, including projects for accelerated oil production,
- evaluate the economic risk (decision tree analysis) and establish probability distribution of NPV,
- classify IOR projects according to maturity (4 groups) and rank IOR-projects within each group according to economy,
- optimize value added (normally NPV).

When bottlenecks within reservoir aspects, surface equipment, infrastructure etc. are identified by the assets, solutions, including new ways of combining known technologies, and proposals for new research projects are sought, in cooperation with the IOR-team.

Since most IOR projects are time dependent, R&D projects will be prioritized according to timing and their potential for adding value. It should also be emphasized that many IOR projects are very complex, with no unique solution. Consequently, company success will depend on its ability to effectively apply experience and skill, the degree of innovation and the application of new technologies.

In order to optimize the field economy it is important to consider IOR over the entire field life. This is a continuous process. The actions implemented are often irreversible and focus should therefore always be on future IOR possibilities.

Methods to be applied may change throughout the field life. Some possibilities are:

- earlier production start-up,
- accelerated plateau build-up,
- increased plateau production,
- extended plateau production period,
- extended tail production,
- reduced economical limit for field shut-in,
- alternative infrastructure for late-stage production, etc.

In order to make the IOR projects more decision-oriented, the risk concept should be incorporated in the economical calculations. A major challenge is, however, to quantify the uncertainties of the main parameters involved. Based on decision-tree analysis a NPV probability distribution should be generated for each project, visualizing up- and downside potentials, see Figure 5. Especially IOR-projects with high upside potential should be carefully considered.

The IOR projects within Statoil are classified by 4 groups, A-D, with projects in group A being most immature. A project is immature either due to lack of proven technology or large uncertainties in the evaluations, see Figure 6. Prioritized projects within group D are close to implementation. Within each group (A to D) the IOR projects are ranked based on economy (NPV and IRR). In order to accelerate the IOR-implementation process further, focus should be on moving the best projects from one group to the next towards the final goal: implementation. The requirements for more detailed studies will normally increase from projects in group A through D.

It is also a challenge to optimize the total value added due to IOR projects. Firstly, the best solution to overcome the different bottlenecks should be identified. The next step is to maximize the value added on a field scale. At this stage special attention should be paid on IOR volumes, checking that the implementation of one project is not reducing the volume of any other project. The final step is to integrate all the IOR schemes in a company IOR strategy. In this last step common use of infrastructure (transportation capacities, process capacities), use of external gas for IOR purposes, etc. should be addressed.

**IOR-POTENTIAL**

**Volumes/Measures**

The IOR-volumes identified through the 1996 study is shown in Figure 7. The high estimate of more than 700 M Sm³ of oil (4.4 billion bbls) comprising fields either in production or with development sanctioned, altogether a total of 40
fields. The expected IOR-volume is close to 500 MSm³ (3.1 billion bbls)

The corresponding IOR-production profiles (Figure 8) show a peak level close to 160,000 Sm³/d (1 million STB/d) around year 2004.

Since nearly 85 % of the potential comes from fields currently in operation the IOR potential is time critical.

The most important contributors to the IOR-volume are, as illustrated in Figure 9, 'smart' wells, gas based methods, water injection * and increased water circulation. It should, however, be emphasized that good reservoir description, and knowledge where to find the remaining reserves, is an important basis for efficiently utilizing these methods. 'Smart' wells comprise a variety of solutions such as horizontals, multilaterals, designer wells, underbalanced drilling and extended reach. The gas based methods comprise WAG (updip/downdip) and various kinds of gas injection (soluble/non-soluble, cyclic, etc.). Increased water circulation takes advantage of reduction in residual oil saturation after waterflooding as a function of cumulative volume injected. Increased requirements with respect to water handling capacity is a consequence of extended water injection.

Maturity
The maturity of the IOR-potential is shown in figure 10. Approximately 60 % of the high estimate IOR-potential proved to be immature (group A).

Economy
Although the spreading in unit costs are considerable, as CAPEX and OPEX depend both on field characteristics, production concept and maturity, an average CAPEX and OPEX unit cost of 1.8 USD/bbl and 0.7 USD/bbl, respectively, were established in order to calculate the economy at aggregated level. These numbers were based on average unit cost pr. method and the relative contribution of each method to the overall IOR potential. A net present value of close to 5 billion USD (1996) after tax with a discount factor of 8% was identified. The NPV is positive even if the IOR volumes turn out to be 50 % less or the costs four times as high as expected. Also a combined case with both 50 % reduction of the volume and 100 % cost increase showed a positive NPV. The discounted break-even price was estimated to be less than 6 USD/bbl.

IMPLEMENTATION

The realization of the significant IOR potential revealed in this study requires the initiation of a large and complex process including all levels and disciplines within the company.

Based on the results of the 1996 IOR-project, Statoil has the ambition to increase the recoverable reserves for fields on production or with proven PDO on the NCS with 700 MSm³ within year 2005 (see Figure 11). In order to obtain this ambitious goal, which is well above the expected IOR-potential, Statoil has investigated what actions have to be taken.

The key factors in this respect are;

- quantify an IOR-ambition for each field,
- formulate field specific IOR-plans required to obtain the overall IOR-ambition,
- develop specific strategies for technology development, qualification and implementation,
- closer cooperation with authorities and partners,
- increased management focus on IOR,
- strategy for financial and human resource allocation.

An overall strategy document was followed up by a plan of action, which in more details outlines the process towards realization of the IOR-ambition. The document includes a number of specific actions, milestones and responsibilities, related to organization issues, technology development, field testing and implementation.

Several assets have now established, or are about to establish, specific plans for implementation of their share of the IOR-ambition. As a consequence several of the largest assets have established dedicated IOR-teams, which work in close cooperation with the operational environment in order to identify technological and organizational

*) Fields or part of fields where water injection has not been applied
issues contributing in the process of improving oil recovery.

Each assets reports annually the status of IOR-implementation. Due to the time critical nature of the IOR potential, special attention is given to the development in the IOR project-portfolio (maturing, implementation).

Status
January first 1996 is the reference date with respect to "book keeping" of IOR volumes. From 1997 and onwards the IOR account is the sum of the IOR potential and the implemented IOR-volume since the reference date.

The 1997 update reporting gave rise to an increase in the high estimate up to 900 MSm³ of oil (5.7 million bbl). The implemented share of the grand total is 275 MSm³ (1.7 million bbl). Figure 11 shows the average oil recovery factor development and Statoil ambitions for fields on the NCS. Also included is the actual oil recovery factor for 1996, which is one percent unit above the ambition. The high estimate IOR-production profiles as of 1996 and 1997 is shown in Figure 12. The increase in 1997 is spread through the given time frame (1997-2028), though dominated by the accelerated production in the period 1997-2005.

One year after the IOR-potential was identified, there has been a significant maturing of IOR-projects. Despite that many IOR-projects already have been implemented, a reduced fraction of the IOR-potential is now classified as immature (group A).

There have only been small changes in the relative contribution from the different IOR-techniques, though gas based methods increases it share of the total IOR-potential.

Summarizing the status of the 1997 IOR-update, the ongoing implementation is on the right track. It should, however, be noted that the best IOR-projects are normally those implemented first. Hence, a number of assumptions, especially within technology development, have to be realized in order to reach the IOR-ambition.

CONCLUSIONS

- a significant IOR-potential from fields on the Norwegian Continental Shelf is identified (more than 700 M Sm³),
- the profitability related to the IOR volumes is very robust, with a break-even price of less than 6 USD/bbl,
- still more cooperation between companies is needed in order to obtain the IOR-ambition,
- realization of the IOR-volumes requires strong focus on technology development, qualification and implementation.

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REFERENCES


*) By implemented means transfer of volumes from potential - to official reserves classification.
Figure 1. Oil production history and prognosis on the Norwegian Continental Shelf

Figure 2. Development in recovery factor for Statoil-operated fields on production.

Figure 3. Multidisciplinary core-team (IOR-team) and network

Figure 4. The IOR-evaluation process

Figure 5. Illustration of decision tree analysis and probability distribution.

Figure 6. Description of Statoil's IOR-maturity classification.
Figure 7. Distribution of IOR-potential

Figure 10. Maturity of the IOR-potential.

Figure 8. IOR production prognosis, for low, expected and high estimates.

Figure 11. Recovery factor development and Statoil ambitions for fields on the NCS.

Figure 9. Distribution of the IOR-potential with respect to technologies.

Figure 12. Light color: The 1996 high estimate IOR production prognosis (see Fig. 8). Dark color: Additional IOR-volumes identified in 1997.