NEED FOR SPEED!

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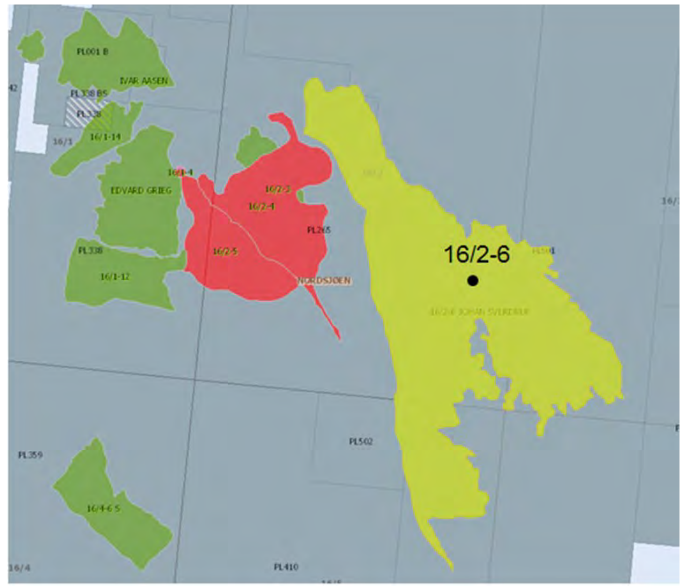
One of the larges oil discoveries ever made offshore Norway, the Johan Sverdrup Field, was discovered by Lundin Norway in 2010. Described in the media as 'World Class Reservoir' with 'Champagne oil' expectations are high. Even though the reservoir is fantastic, it doesn't drain itself and various IOR methods had to be evaluated. One method that was studied, and still being considered, is polymer flooding. Lundin Norway carried out a polymer evaluation project with TIORCO to find a polymer suitable for Johan Sverdrup, obtain polymer characteristics for dynamic simulations and do initial evaluations. Polymer flooding cases with alternating gas injections are very calculation intensive and simulation time increased far beyond the time available in the project. This show stopper had to be eliminated in order to complete the study on time.

The Johan Sverdrup Field

Johan Sverdrup was discovered with the well 16/2-6 drilled by Lundin Norway. The field is situated about 140 km West of Stavanger and cover some 200 km2 stretching into 3 licenses. The reservoir is relatively homogeneous with high to very high permeability. Reservoir pay is 70m in the thickest parts. The oil is strongly undersaturated and has a moderate viscosity. On February 13th 2015 the PDO was submitted by the partnership Statoil (Operator), Petoro, DetNorske, Maersk and Lundin Norway. This mega development is estimated to cost 170-220 bNOK and total income from sales products 1.350 bNOK. In the first development stage a field centre consisting of 4 platforms will be ready in Q4 2019. Water will be injected via 3 subsea templates for pressure support. Concept for the following development stages is still being evaluated. Even a small percent increase in recovery on this large field can generate significant extra revenue to the part-



The Johan Sverdrup field was discovered in 2010 when Lundin Norway drilled the well 16/2-6. Later appraisal drilling by PL265 operator Statoil and PL501 operator Lundin Norway revealed this large field extending some 200 km2.(Picture: NPD factmaps)

Johan Sverdrup Field Centre in phase 1 with riser platform, drilling platform, process platform and living quarters (Picture: Johan Sverdrup konsekvensutredning) ners, the Norwegian government and people.

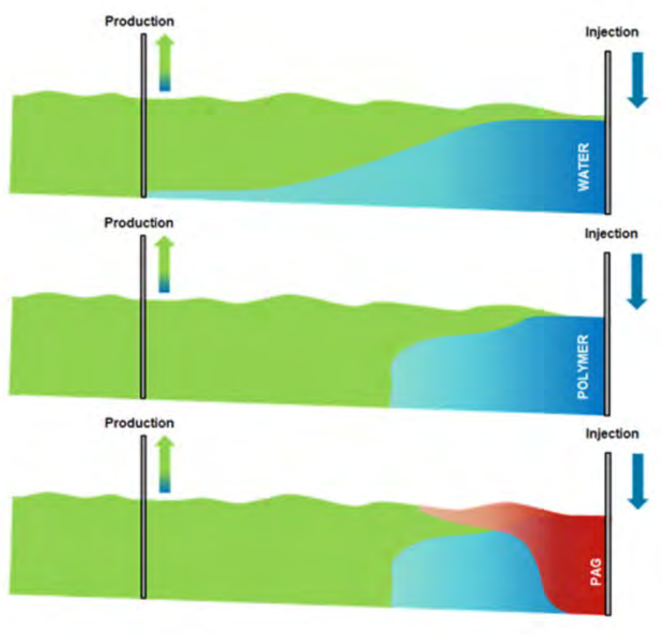
Polymer project

Given the moderate viscosity in this field, the water-oil mobility ratio suggests that polymer flooding may have an effect. By adding polymer to the injected water it will become more viscous, hence, the water-oil mobility ratio more favourable resulting in less fingering and a more piston like water front with lower oil saturation behind the front. Several polymers were screened based on their properties. Lab experiments were done on five selected polymers to investigate thermal stability, viscosity at different polymer concentrations, screen factors and compatibility with formation and injection water. Finally, one polymer was selected for core flood experiments with both sea water and low salinity water. A numerical model of the flooding experiments was history matched with lab results providing a set of keywords describing polymer-rock properties, adsorption and degradation. This characterization is used in the full field simulation and enables calculation of polymer concentration and water viscosity of each grid cell.

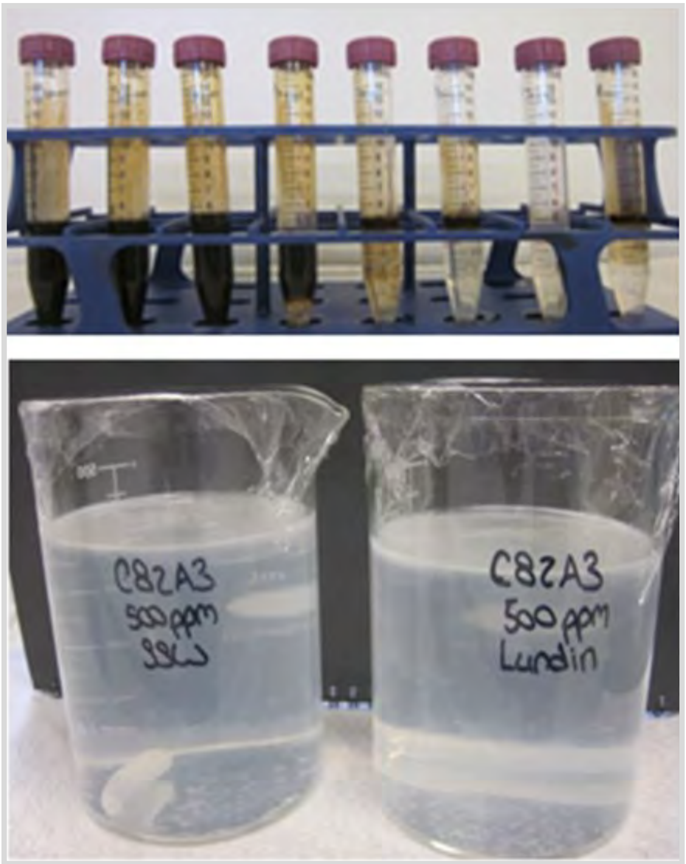
Implementation of lab results in simulation model

The bumpy ceiling of the reservoir implies that there may be attic oil not swept by the water or polymer flooding. Polymer Alternating Gas (PAG) was therefore considered in the study. Full field simulations with polymer flooding took long time, but alternating with gas dramatically increased the simulation time. It would be impossible to complete the study on time with full field simulations taking almost one week. An alternative plan to speed up simulations was needed. Rock Flow Dynamics (RFD) had earlier demonstrated their fast simulator, tNavigator, and was contacted regarding this challenge. Polymer functionality was not supported at the time. However, RFD saw this as a natural development and entered a project with Lundin Norway to develop the required functionality. Within a couple of months a version was ready, tested and verified. Simulation time

$$M = \frac{k_{rw}}{\mu_w}\frac{\mu_o}{k_{ro}}$$



Conceptual illustration showing average saturation when water flooding, polymer flooding and flooding polymer alternating gas. Notice the delayed water break through for polymer and the recovery of attic oil when alternating with gas

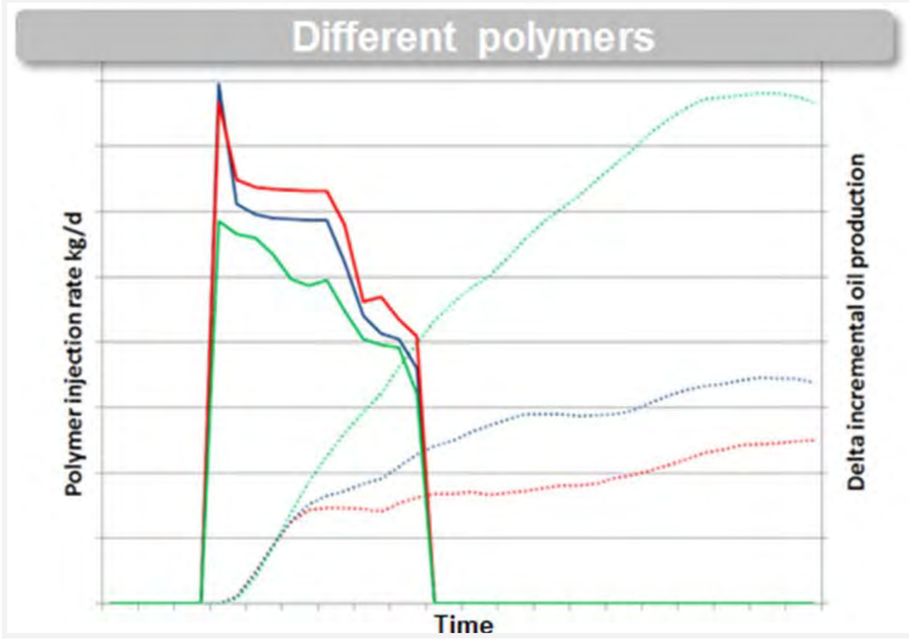


Testing of polymers was done by TIORCO

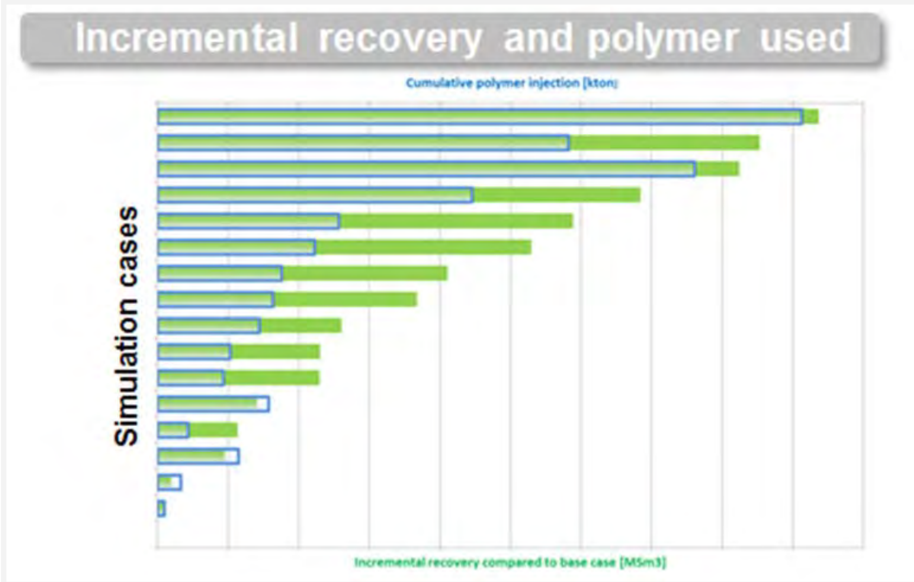
was reduced by astonishing 75-85% on a regular dual CPU workstation with 16 cores on board. The key advantage of tNavigator is the simulation speed. The technology is designed to maximize the parallel performance on the modern multicore hardware. The license price does not depend on the number of cores in the workstation, so the available computational resource could be utilized efficiently. tNavigator supports the conventional simulation model formats. Therefore, the project team did not loose any time on input data conversion as the existing model could be loaded as is. With the new simulator in place multiple sensitivities were run in order to quantify the effect of polymer. Sensitivities covering polymer injection in selected injectors vs all, selected areas vs all field, timing of polymer injection, variation in polymer concentration and polymer injection vs polymer alternating gas. Economical evaluation of the cases was done to gain some insight to what would be a good polymer strategy.

Summary and observations

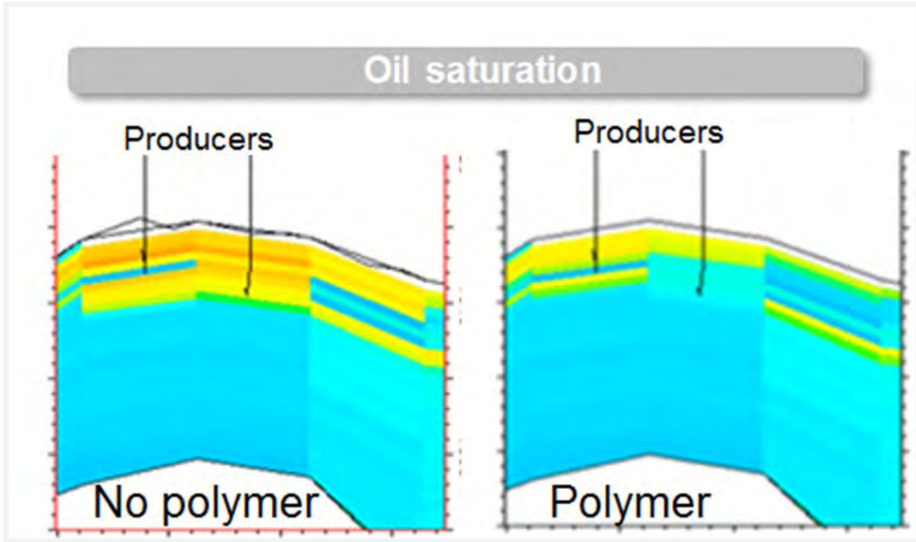
The polymer experiments performed by TIORCO provided input to the simulation model. Changing the simulation platform to tNavigator reduced simulation time with up to 85% on a workstation enabling simulations to be completed within the given timeframe. This initial study proved useful and more detailed IOR studies are ongoing and managed by the Working Operator. It is premature to conclude, however some observations are worth mentioning. Polymer flooding had a positive effect in all cases. No sensitivity was done on the polymer properties; hence, results could change if e.g. polymer were to degrade faster in the reservoir than anticipated. The study showed that production increase comes several years after polymer injection starts. Rough estimates for operating cost and capital investment where available at the time of the study, so any conclusion regarding project economics is premature. However, observations suggest it may be challenging to make it economically attractive in some cases since the additional revenue from polymer flooding comes late. The study shows that the gain is not equal in all parts of the field. Incremental recovery vs polymer used suggest that polymer injection in selected areas only is more economically favourable than polymer injection in all injectors. Polymer alternating gas also indicated an upside potential, but this complex scenario needs further studying and optimization before any conclusions can be made. Prior to any investment decisions more detailed reservoir studies are required in addition to studies covering polymer type and properties, logistics, operations, handling of produced polymer and HSE aspects.



Varying polymer injection rate and resulting increase in production is shown above. Notice the delay in production increase



The figure shows the ratio of polymer used and incremental recovery for various cases. Cases are made anonymous, but the figure illustrates the wide range in polymer flooding efficiency



A cross section showing oil saturation with water flooding and polymer flooding. Notice there is some attic oil left that could be drained with gas