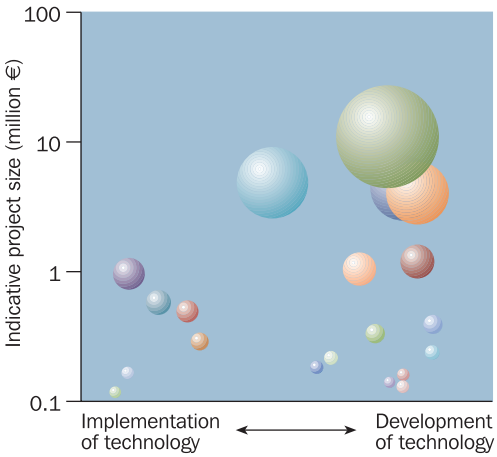
PRODUCTION OPTIMIZATION

TNO innovation for life

Maximising the recovery from new and existing oil and gas fields is one of the key challenges for E&P operators. TNO develops and implements technology solutions with industry partners and/or academic institutions to optimize oil and gas production. These solutions cover issues that may arise in the *daily operation* of wells and facilities (e.g. slugging of wells, deposition of salt, managing riser integrity), support the *optimum development* of oil and gas fields (how to identify unconnected reservoir compartments, or how to place wells optimally) or relate to the development of *new methods and processes* (e.g. smart sensors or innovative monitoring and control schemes). TNO not only develops and implements innovative solutions, it also develops and manages world-class R&D programs. We pride ourselves in being able to find solutions for any issue that technology may be able to address and enable an increase in the hydrocarbon recovery from your fields through state of the art technology.



TNO

TNO is one of Europe's largest independent companies in the areas of technology development and technical consultancy. The last 30 years TNO has been active in the oil and gas industry. With around 3,500 engineers and scientists, TNO is working in a wide range of economical sectors, including energy, mobility, industrial innovation, information society, health and defense. TNO has more than 80 years of experience in advisory, in which independent from commercial interest, innovative technologies in close collaboration with major industrial parties and universities have developed and knowledge transfer programs have been implemented.

In the oil & gas sector we hold over 30 years of experience in working with operators and service companies around the world. Our work in the energy sector includes:

- Production optimization of oil and gas assets
- Integrity of installations and equipment
- Water treatment and desalination
- Instrumentation development
- LNG
- Reservoir studies
- Carbon Capture & Storage and Utilization (CCS)
- Gas treatment
- Geosciences
- Exploration.

Our customers are major international oil companies like Statoil, Shell, and Lukoil; as well as large independents such as Wintershall and Maersk Oil. TNO has been active in the Middle East for several decades, working with or for national oil companies such as Saudi Aramco, ADNOC, PDO and KOC. Since 2011 TNO serves its customers from The Qatar Branch Office in Doha.

The range in project size and the extent of technology development of recent production optimization projects that TNO got involved in is indicated above. Specific projects are:

a. A roadmap for the implementation of smart field operations;
b. A study on coning control for a large international operator;
c. A long term collaboration agreement with Maersk to jointly develop new technologies for increased oil recovery (IOR). Focus will be on long horizontal wells and increasing oil recovery through integrated operations and production optimization;
d. Development of a fiber optic flowmeter for Shell;
e. A joint industry project on Liquid Loading with Dutch Operators;
f. Development of innovative sensor materials for a large American consortium.

PROJECT EXAMPLES

Three examples are covered in more detail:

- An ongoing project with Wintershall to develop and implement a real-time production monitoring and optimization system in which a significant increase in yearly production as further detailed in SPE paper 128300 has already been realized.
- A study / development project that relates to the use of subsidence data to identify un-drained areas of a producing field in the Netherlands (SPE paper 134457).
- The ISAPP research program that relates to the development of smart oil field technology jointly with the TU Delft.

REAL-TIME MONITORING OF NORTH SEA GAS ASSET

HANS REIJN, PRODUCTION ENGINEERING SUPERINTENDENT, WINTERSHALL NOORDZEE B.V.

German oil and gas company Wintershall, which is a subsidiary of chemical giant BASF, asked TNO to assist in the development of an intelligent production monitoring system for its North Sea gas assets. Such a system continuously acquires measurement data from the off-shore asset in order to optimize production by offering real-time decision support to operators and engineers. 'With good results', says Hans Reijn, Production Engineering Superintendent at Wintershall. 'We will be able to recover the costs of this project very quickly.' The results have been published in an SPE-paper (SPE 128300).

In October 2008 Wintershall and TNO started a pilot project in section F16A (offshore North Sea). This has given much better insight into all kinds of operational issues. The gradual decline in production capacity due to salt build-up in some wells of the asset, which is difficult to predict, is one of them. 'By constantly checking the ideal situation against the real

Real-time monitoring of North Sea Gas Asset.

WINTERSHALL: 'WHAT TNO ALSO OFFERED WAS A NICE COMBINATION OF THOROUGH THEORETICAL KNOWLEDGE AND A VERY PRAGMATIC APPROACH, AN URGE TO SOLVE PRACTICAL PROBLEMS'

situation, we can more precisely plan the right moment for maintenance'. Other improvement relate to an improved understanding of the long term decline in reservoir pressure and the identification of opportunities for compressor performance improvement.

The development of production monitoring systems asked for combining commercially available monitoring systems, with in-house production models of Wintershall and real-time monitoring methods that were developed by TNO. 'What TNO also offered was a nice combination of thorough theoretical knowledge and a very pragmatic approach, an urge to solve practical problems' says Hans Reijn. 'We had several options available to hire in IT knowledge but TNO has the distinction of having much more in house, a wide spectrum of knowledge, including gas production, which was a must in this case.' 'TNO's flexibility in this project has been a real strong point. Interim adjustments were never a problem. Our team's priority is day-today gas production. Projects, no matter how vital, always take second place. TNO constantly displayed the flexibility and understanding that took account of our priorities'.

'URGE TO SOLVE PRACTICAL PROBLEMS'

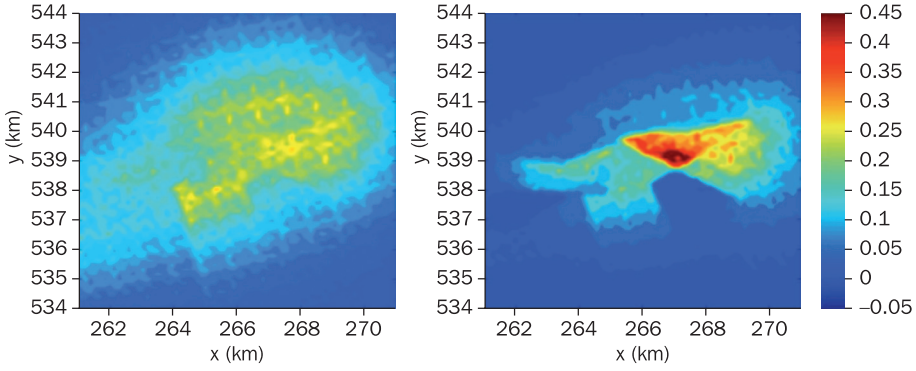
USE OF SUBSIDENCE DATA TO QUANTIFY RESERVOIR COMPARTMENTALIZATION (SPE 134457)

Surface subsidence can be used as a reservoir monitoring tool. This was demonstrated by a field study on the Roswinkel gas field. Subsidence data were used to reduce the uncertainty about the reservoir architecture. The Roswinkel gas field in the northeast of the Netherlands was in production from 1980 to 2005. Located at about 2100 m depth, it is a severely faulted anticlinal structure, constituting up to 30 reservoir compartments. As a result of its complexity there are large uncertainties about the fault transmissibilities and the strength of the connected aquifer. Consequently it is possible that there are undepleted compartments in the reservoir. Pressure depletion due to gas production causes the reservoir sandstone to compact, leading to surface subsidence. The gas production in Roswinkel has induced subsidence of approximately 17 cm above the center of the field. The subsidence at any point on the surface is a result of compaction over a large area within the reservoir.

The compaction of reservoir was estimated using subsidence data in order to reduce the uncertainties about fault transmissibility and aquifer connection. The subsidence data had been obtained from leveling campaigns and satellite measurements (persistent Scatterer InSAR). A Bayesian inversion method in which prior knowledge is combined with observations is used. Estimates on the compaction and the associated uncertainties were generated by Monte carlo simulations of the reservoir in which the fault transmissibilities and aquifer connectivity varied. Geological reality was maintained and the production history was honored.

The results of the field study indicated a reservoir in which certain large faults divide the reservoir into compartments with different pressure histories vis-à-vis a relatively smooth field extending in the acquifer when considering production data in isolation. In addition, the aquifer activity appeared to be much weaker in comparison to earlier results.

The field study demonstrated that a carefully executed inversion exercise can considerably reduce uncertainties, thus making it possible to identify possibly undepleted compartments in the reservoir.



Comparison of the a priori compaction model (left) and as per the inverted compaction model (right). The a priori model has faults at fixed positions but variable transmissabilities and therefore the expected compaction profile is smooth and extends far into the aquifer. The inversion technique establishes the fault characteristics and suggests reservoir compartmentalisation.

JOINT INDUSTRY RESEARCH PROGRAM

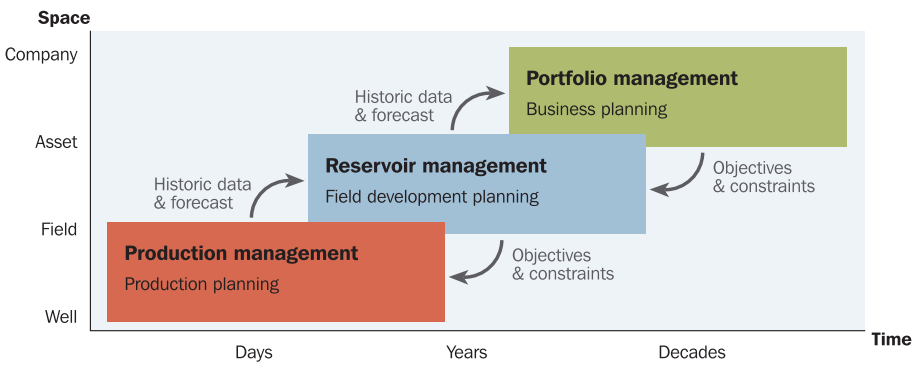
ISAPP

Inspired by the systems and control theory used in meteorology and the process industry, a program between Shell, TU Delft and TNO was started to develop methods for reservoir model updating and production optimization based on data from various sources, such as production sensors and time-lapse seismic.

The project has run for four years (2005-2009) and consisted of fundamental knowledge development by 30 PhD students & research staff at the Technical University of Delft, knowledge & tool development by TNO and application of developed knowledge in projects & demonstrators by TNO and Shell. The main objectives of this program were:

- To generate significant innovations in the Exploration and Production (E&P) process through the application of system-dynamic thinking and model based control concepts .
- To generate the intellectual framework, concepts, models and algorithms to enable real time model based closed loop reservoir management, and to test these on virtual and real assets.
- To develop tools and techniques for 'smart' production systems where measurement and control functionality adds significant value, and to test these on virtual and real assets.
- To perform research beyond the state-of-the-art in the E&P industry and to introduce innovative elements from other industries.

Following the initial success, TNO and the Technical University of Delft are starting up a new ISAPP program with multiple sponsors. To date ENI, Statoil and Petrobras have joined the program.



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