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DEVELOPMENT OF RESERVOIR SIMULATION MITTELPLATE – A CHALLENGE FOR TECHNOLOGY

1. THE MITTELPLATE FIELD

The Mittelplate is located approximately 150 km north of the city of Hamburg, in the delta of the Elbe river. Since October 1, 1987, oil has been produced from the ecologically sensitive "Wattenmeer" national park without incident (Fig. 1). By July 2005, some 15 million tons of crude had been produced. The location of the field inside a national park represents many challenges for the operator consortium in their effort to produce oil without any accidents and in an environmentally compatible manner. The consortium faces up to these challenges by using state-of-the-art technologies and methods.

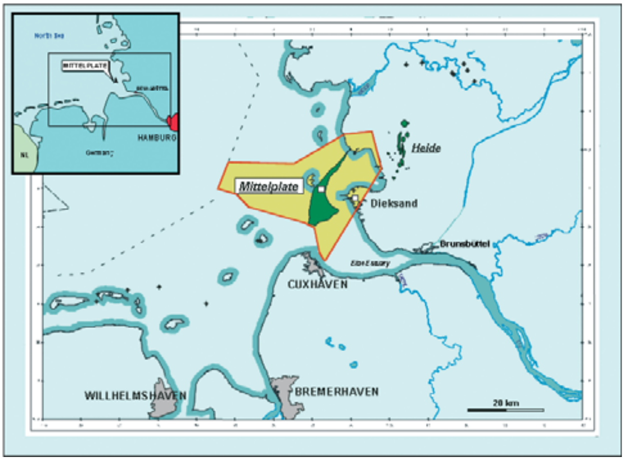

Fig. 1. The location of the Mittelplate field

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Mittelplate is of central significance for Germany's petroleum production, since the field contains approx. 70% of the country's oil reserves. Currently the field produces about 60% of Germany's crude oil (see Fig. 2). A consortium made up of RWE Dea AG as operator and Wintershall AG is developing the field using leading-edge technology.

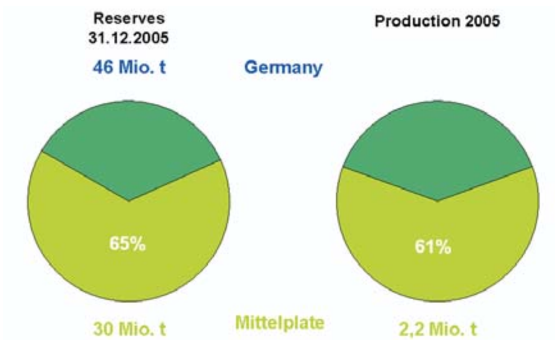

Fig. 2. Germany's reserves and production of crude oil

The existence of the Mittelplate oil reserves was proven for the first time in 1964 by Dogger Büsum 1 well. In the period between 1980 and 1981, three more wells confirmed the find and showed quantities of oil that could be produced economically. Based on the findings of these three exploratory wells, it was decided to build a production platform on the site of the Mittelplate 1 well that is unique in the world: the platform is an artificially constructed island. From 1987 until today, 21 wells have been sunk from the platform into the reservoir.

In addition to the island-based production, parts of the oil field have been tapped through seven long, horizontal wells drilled from the mainland (Fig. 3). Some of these wells are ranked among the top 10 of the longest extended-reach wells in the world. The longest well is 9 km long. The wells from the mainland were sunk between 2002 and 2003.

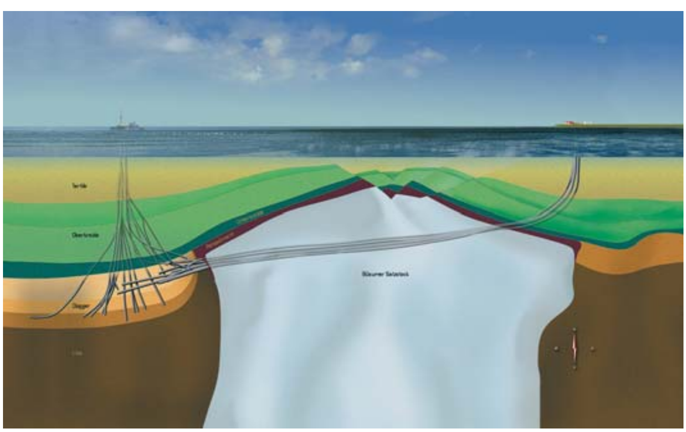

Fig. 3. Development concept for Mittelplate

In September 2005, a pipeline was laid linking the Mittelplate production platform to the Dieksand Land Station in order to provide an even safer method of transporting the oil to shore. The previous method of transporting the oil in tankers, which had been in use for almost 20 incident-free years, has thus been made redundant by the pipeline. Construction of the pipeline also marked the start of a new era in the production for the island: the pipeline makes it possible to keep the production rate constant and so reduce production shortfalls. Transportation using tank barges was very much dependent on prevailing tides and weather conditions, which meant transports frequently had to be suspended.

In December 2005, a new drilling rig was also installed on the island. This rig makes it possible to safely drill wells even into the more distant sections of the field that had been out of reach for the old drilling rig.

2. RESERVOIR CHARACTERISTICS AT MITTELPLATE

The Mittelplate field consists of three different reservoirs:

1) Dogger Epsilon/ Delta,
2) Dogger Gamma,
3) Dogger Beta

The reservoirs are located at depths ranging from 1800 to 2800 meters (see Fig. 4).

The sandstone deposit was created during the Middle Jurassic and was shaped by the intrusion of the Zechstein salt. The reservoir is adjacent to the main slope of the Büsum salt diapir. This creates problems in the seismic description of the reservoir and also by production from the reservoirs.

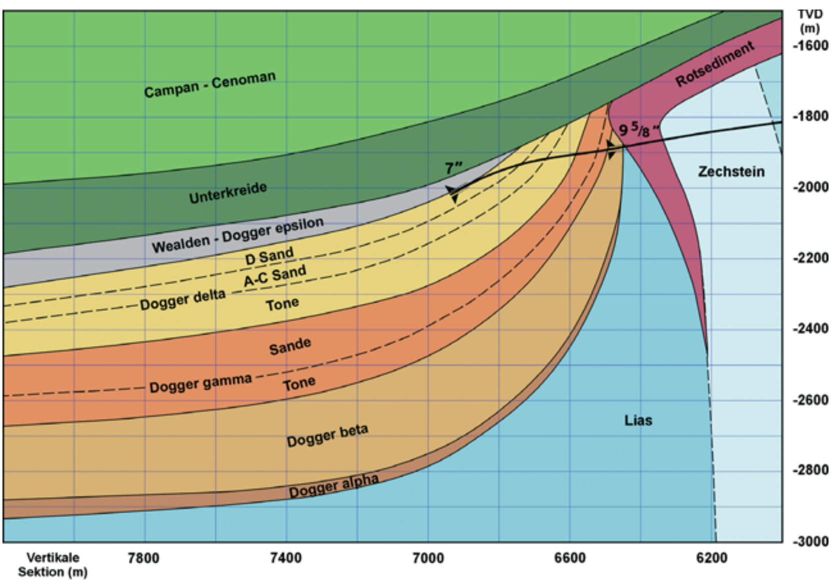

Fig. 4. Structure of the Mittelplate deposit

The three reservoirs within the Mittelplate field have very different production and reservoir characteristics (see Tab. 1). The level of development of the individual reservoirs also differs considerably.

Table 1

Overview of Mittelplate reservoirs

	Permeability [mD]	Aquifer	Wells
Dogger Delta/Epsilon	2000–10000	Yes	Sunk: 2 injection wells and 12 production wells Planned: 2 to 3 injection wells and 2 production wells
Dogger Gamma	60–500	Yes	Sunk: 3 production wells (2 re-completed) Planned: 1 production well
Dogger Beta	20 –300	No?	Sunk: 3 injection wells and 6 production wells Planned: 20 to 25 production wells; 10 to 15 injection wells Re-completion of existing wells

The Dogger Beta reservoir extends over an area of approx. 60 km^2, which makes it the largest of the three reservoirs. It is also the least developed of the reservoirs at this point. For this reason, up to 30 additional production and injection wells are planned for this reservoir. Improving the oil extraction rate from this reservoir requires vast amounts of injection water. The Dogger Beta wells are currently producing at a rate of approximately 250 m^3/d. The degree of the water cut and the production rate depends heavily on the amount of water injected, since the Dogger Beta reservoir has no known aquifer. The water injected here comes mainly from water extraction from the production wells in the reservoir. An increasing proportion of this water is produced from the wells in the Gamma und Dogger Epsilon/ Delta reservoirs.

The Dogger Gamma and Dogger Epsilon/Delta reservoirs have already been developed. Plans are under way to sink one well into Gamma and four wells into Epsilon/Delta. Unlike Dogger Beta, these wells show production rates of up to 1000 m^3/d. These reservoirs also have an aquifer that provides supplementary pressure. The injection into Dogger Epsilion/Delta serves primarily to supplement and stabilize pressure. The Gamma reservoir is currently producing from one well and therefore does not require any additional pressure.

The reservoirs have very different characteristics, and as a result of water re-injection the reservoirs are strongly interdependent in terms of their behavior. Limited injection water will be extract from other aquifers.

3. RESERVOIR SIMULATION

3.1. Challenges faced in running reservoir simulations

Producing reservoir simulations for the Mittelplate field presents a number of different challenges. These relate particularly to the difficulty of (geological, geophysical) descriptions of the reservoirs, to the interdependence between the different reservoirs, and to the well completion technologies used in the development.

The reservoirs have a large domain of uncertainty due, among other things, to the seismic resolution near the salt diapir, and to the well interferences and their dynamic density. These uncertainties in the description of a reservoir represent a major challenge for the history match update for the reservoir. In addition to the problem with the existing history match, the development of Dogger Beta presents additional challenges for the reservoir simulation. The new wells are planned to be located primarily in an area free of dynamic factors, and this makes it difficult to use the history match to provide information about the density of the interferences and about the structure of the reservoir (see Fig. 5).

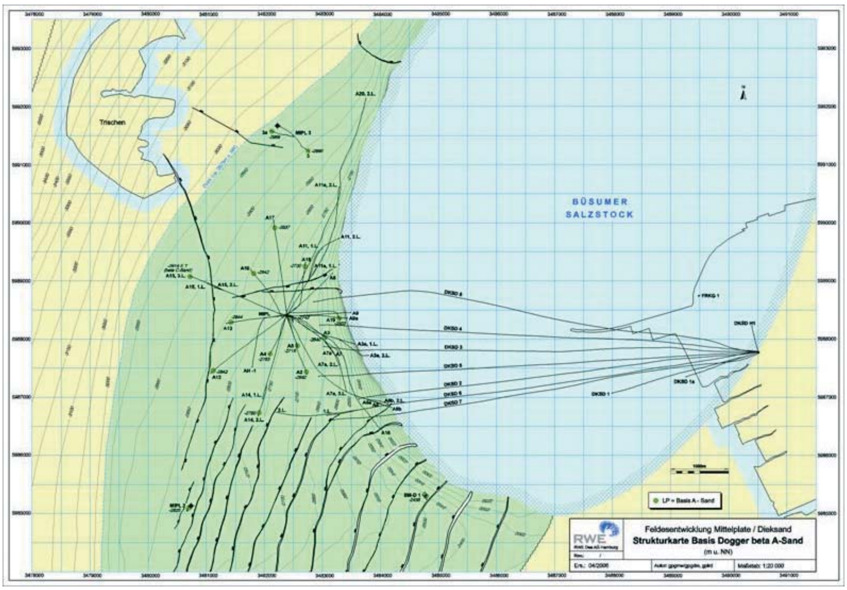

Fig. 5. Structural map of Dogger Beta reservoir

The interdependence of the reservoirs presents a further challenge. This is particularly important when making forecasts. The reservoirs affect each other's behavior as a result of the water injection and production. This factor must be included in the simulation in order to allow the future development of the reservoir to be optimized.

The technological challenge affects both the history match and the forecasts made. On the one hand, more and more complex completions are fitted inside the wells in order to optimize oil extraction from the reservoir. For example, in the Mittelplate 21 well, an intelligent well completion was fitted, making it possible to extract oil from different zones with varying drawdown and production rates. It is not only the inclusion of these wells, but also the inclusion of the other existing extended-reach wells that presents a challenge for the simulation. Some of these wells have perforation intervals of several 100 m, and the distance between pump and perforations interval can amount to several kilometers. This affects the reservoirs on the one hand, and the production characteristics of the well on the other. Linking the reservoir and borehole models is therefore unavoidable if we are to describe this effect in the history match and in the forecast.

3.2. Development of reservoir simulation for Mittelplate

The development of the reservoir simulation for Mittelplate is linked on the one hand to the increasing challenges and new insights, and on the other to the development of computer hardware and software technology. Table 2 provides an overview of the history of hardware and software development at RWE Dea.

Table 2

Hardware and software development

Period	Hardware	Used Software
1980…	Mainframe	Beta II; Eclipse
1990…	Unix –serwer Unix – Workstation	Eclipse inclusive Pre- and Postprocessing
2000	Unix –serwer Windows PC	Eclipse inclusive Pre- and Postprocessing Zusatzliche Software

Developments in reservoir modeling paralleled those in hardware and software. The first models produced only considered individual sections of the reservoir in order to determine recovery factors and the best method for exploiting the reservoir. As early as the late 1990s, full-field models were produced, and different geological realizations were used to depict the influence of geology on the production characteristics of a reservoir. This type of risk analysis was carried out especially for the development of the Dogger Epsilon/Delta reservoir and its extended-reach wells. Table 3 is an overview of the historical development of reservoir models and their specific purposes.

Table 3

Development of reservoir models

1981	1000 active blocks	Dogger Beta	Determination of injection concept and well grid Production forecast
1981	700 active blocks	Dogger Delta/ Epsilon	Simulation of a well test Production forecast
1985	720 active blocks	Dogger Beta	Production forecast
1993	720 active blocks	Dogger Beta	Comparison between horizontal and vertical wells
1998	52000 active blocks	Dogger Gamma	Production forecast Domains of uncertainty in reservoir descriptions
1999	23700 active blocks	Dogger Delta/ Epsilon	Field development Dieksand Multiple geological realizations

3.3. Reservoir simulation and modeling today

Modern reservoir simulation tackles the challenges by building more complex models, using state-of-the-art computer technology and software. Table 4 provides an overview of the existing models. All reservoir models contain multiple geological realizations in order to describe the uncertainties in field development. A geological realization is an equal-probability distribution of geological parameters (e.g., porosity, permeability) in a structural model. All geological realizations share equal probability at this point in time and result in different forecasts, especially for new wells. The greatest number of realizations are available for Dogger Beta, as this reservoir has the highest level of uncertainty.

Table 4

Overview of the current status of models

	Grid blocks	Computing times	Particulars
Dogger Beta	active blocks 83000	History match: 45 minutes Prediction: 1 hour for 30 years	In production since 1987 Water injection 25 geological realizations
Dogger Gamma	active blocks 155000	History match: 2.5 hours Prediction: 3 hours for 30 years	Reservoir with steep incline along salt diapir Aquifer effect Only one primary production well 4 geological realizations
Dogger Delta/Epsilon	active blocks 200000	History match: 3–4 hours Prediction: 7 hours for 30 years	Reservoir with steep incline along salt diapir Aquifer effect and water injection Production increase since 1998 8 geological realizations

In addition to generating a large number of realizations, software is also used to describe the uncertainties. This software permits quantification of geological and geophysical uncertainties during a history match. It also makes it possible to carry out probabilistic estimates of reserves and the evaluation of the uncertainties from the history in order to make forecasts. The software is based on Bayesian statistics and the experimental design method. These particular methods are used not only in reservoir simulation, but also in many other fields of science and industry, such as finance, medicine, and by NASA. The approach chosen by RWE Dea must not be confused with the so-called Automated History Match Tools: our method allows users to select parameters and gives them the option to affect outcomes. The program helps users produce the history match as well as generating the probabilistic estimate of reserves by means of a sensitivity analysis and a statistical investigation. This type of analysis and investigation is only possible through multiple simulation runs. State-of-the-art computer technology is used to generate these multiple simulation runs. At RWE Dea, we use a grid computing system that controls the efficient distribution of simulation runs to several computers and to a cluster. This makes it possible to have multiple simulations running in parallel. It also allows large-scale models to be run on several processors operating in parallel. Using this method, we reduced the computing time for Epsilon/Delta from 7 hours down to 1 hour, using 8 processors running in parallel.

Using a combination of hardware, software and complex modeling, RWE Dea employs reservoir simulation as a tool to improve field development and to optimize production in future.

Figure 6 shows the ratio of water injection to oil produced, water to oil produced and produced to injected water. This illustrates the difficulties in reservoir simulation concerning dependcy of reservoirs from each other. Figure 6 shows the ratio for only one geological realization. Figure 7 shows seven different oil cumulative production profiles depending on different geological realization and field development plans for Dogger Beta reservoir. These forecasts are some equal and the based history matchs are comparable.

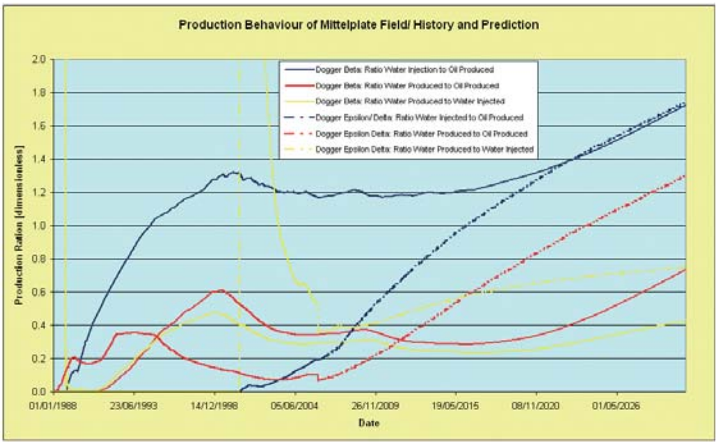

Fig. 6. Ratios of Injected to Produced Water, Water to Oil Produced and Water produced to Water Injected for Dogger Beta and Epsilon Delta

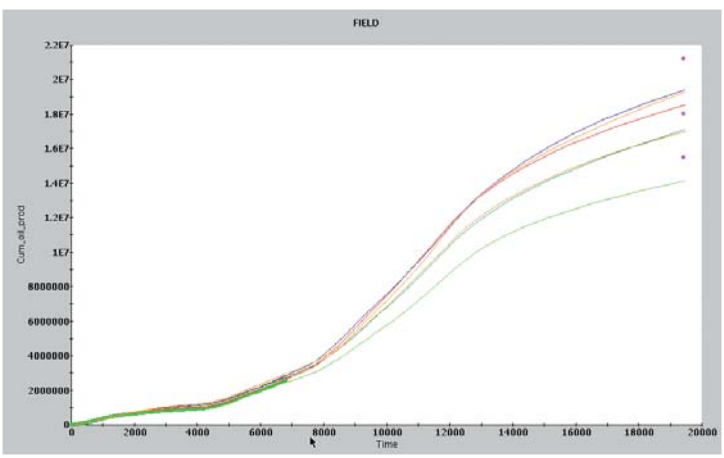

Fig. 7. Influence of Different Geological Realizations and Different Field Developments on Cumulative Production Dogger Beta

3.4. Future developments and challenges for reservoir simulation in the Mittelplate field

The development of simulation technology will continue, as it has in previous years. New computer and software technologies will have an impact on the way reservoir simulation is done. On the hardware side, we can expect more and more powerful computers that will make it possible to create models of ever-increasing complexity. These developments in computer technology may well make the need for today's practice of upscaling our models redundant in future. In the software area, new mathematical stochastic methods will be used to improve estimates of the degrees of uncertainty. There will also be developments in methods to improve the generation of history matches even further. Future software and hardware developments will allow us to couple separate models, e.g. reservoir, borehole and engineering models, in order to produce timely forecasts.

For Mittelplate, the development of innovative fluid flow models for use with boreholes and with the pipeline will make an essential contribution to field development. The ability to couple individual models and assess their effects on forecasts is an important issue in a field such as Mittelplate, where field development is proceeding from several locations and where the behavior of the individual reservoirs is markedly different, yet interdependent.

Reservoir simulation must also take the planned well-drilling program into account. In the Dogger Beta reservoir, 2 to 3 new wells will be sunk each year, starting in 2008. These wells will generate new data which will update the geological and simulation models and thus have an effect on future predictions. Furthermore, new borehole concepts, such as dual or multilateral wells, will need to be integrated into the models in an effort to optimize forecasts.

Another major issue to be confronted in connection with the future of reservoir simulations at Mittelplate is data handling. With up to 30 new wells planned for the future, there will be increasing volumes of data that need to be handled and processed. This presents a challenge in terms of the complexity of the models as well as in terms of the hardware and software. A further issue to be addressed is how up-to-date our models can be. Should the models operate in real time, or should they be designed to provide answers at the right time? These are questions that need to be answered in the field of reservoir simulation in general, but also more specifically in relation to Mittelplate. One answer is that simulation should guide day to day operations and help to improve field development.

The development of reservoir simulation will progress ever more rapidly and continually present us with new challenges. For this reason, RWE Dea will do everything possible to apply the latest reservoir simulation technologies in order to optimize predictions and estimates of reserves for Germany's most important oil field.

4. SUMMARY

Mittelplate, Germany's most important oil field, consists of three separate reservoirs which are interdependent in terms of their behavior as a result of their linkages in water production and injection. The field is located in an ecologically sensitive area and has

therefore been developed using leading-edge technologies. Production commenced 1987 and has been incident-free ever since.

The development of reservoir simulation for the Mittelplate field was closely linked to the development of hardware and software available for this purpose. Today, our reservoir simulation takes advantage of state-of-the-art hardware and software and is capable of running complex full-field models. One of the primary goals is the provide estimates of uncertainties in development of the field, as well as to integrate the interactions between the individual reservoirs into the models so as to assess their effect on future development. This is achieved by using multiple geological realizations in our reservoir simulations. Running reservoir simulations on the latest hardware and software makes it possible to use a multi-scenario approach in an effort to optimize the development of the reservoirs and the exploitation of the reserves. In developing the Mittelplate field, RWE Dea AG is making use of leading-edge computer hardware and software. Reservoir simulation is critical to optimizing field development and maximizing value of the Mittelplate business asset.