Hydraulic fracturing : application of best practices in Germany

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Hydraulic Fracturing – Application of Best Practices in Germany

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Abstract

Today, many oil and gas fields would not be economically viable without hydraulic fracturing. For more than 50 years, the technology has been applied by the oil and gas industry in Germany without any negative impact to the environment (WEG 2013). However, due to an increasingly critical public perception, the approval of recent oil and gas projects requiring hydraulic fracturing has been adversely affected by a political de-facto moratorium. Best practices have been developed for planning, permitting and execution of projects involving this technology including active stakeholder engagement. The Düste Z10 Tight Gas Project, operated by Wintershall, is currently idle as the approval of required hydraulic fracturing operations is outstanding. Best practices applied in the project are described and discussed.

Zusammenfassung

Seit 1949 wird Hydraulic Fracturing in mehr als drei Millionen Bohrungen weltweit angewendet. Allein in Deutschland ist das Verfahren seit 1961 mehr als 300-mal ohne negative Auswirkungen auf das nutzbare Grundwasser zum Einsatz gekommen. Die Technologie ist ausgereift und stellt bei Einhaltung betrieblicher Best Practices kein Risiko für die Umwelt dar. Diese sind im Wesentlichen: 1. die sichere Prognose dichter Deckgebirge, 2. die Vermeidung des Eintrags von Schadstoffen von der Erdoberfläche in das Grundwasser, 3. die Gewährleistung integrer Bohrungen, 4. die sichere Prognose und Steuerung der Ausbreitung hydraulisch induzierter Risse, 5. die Verwendung von Frac-Fluid-Additiven mit maximal WGK 1-Einstufung und Offenlegung dieser, 6. die sichere Entsorgung von rückgeförderten Flüssigkeiten sowie 7. die Vermeidung spürbarer, ausgelöster seismischer Erschütterungen. Anhand des aktuellen Tight-Gas Projektes Düste Z10 in Norddeutschland werden Beispiele für die Anwendung dieser Best Practices aufgezeigt und diskutiert.

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1 Introduction

Since its first application in the 1940's (Montgomery & Smith 2010), oil and gas companies have been using hydraulic fracturing as the technology of choice for production enhancement. Originally developed to bypass drilling induced near-wellbore damage, it has been continuously refined to effectively increase the drainage area of a well. Hydraulic fracturing improves recovery factors from conventional reservoirs, especially those in decline, and is the key technology enabling commercial production from unconventional reservoirs. To date, close to three million wells worldwide have been hydraulically fractured and the technology is applied to 60% of all newly drilled oil and gas wells (Montgomery & Smith 2010). About 35.000 new wells are drilled in unconventional reservoirs in the USA per year alone (WEG 2014). In Germany, hydraulic fracturing has been applied by oil and gas companies since the 1960's with more than 300 operations carried out to date (WEG 2014).

2 Tight Gas Project Düste Z10

Wintershall Holding GmbH, a 100% oil and gas subsidiary of BASF SE initiated the Düste Z10 Tight Gas Project in Northern Germany in 2011. The gas well location is in Wintershall's 100% production license Ridderade-Ost in the State of Lower Saxony, about 50 km south of the city of Bremen. The project is mainly comprised of the following stages:

- Drilling and completing a vertical well into the tight Carboniferous sandstones;
- Carrying out a comprehensive data acquisition program;
- Hydraulically fracturing gas bearing sands within the Carboniferous;
- Carrying out a long term production test to determine the commercial production potential.

The target formation in Ridderade-Ost is known to Wintershall from two previous wells. The well Düste Z7 was drilled in 1966 and proved gas in the Carboniferous. However, only sub-commercial production rates could be achieved from a vertical open-hole test. The well was therefore plugged back. In 1995 Wintershall started another attempt at the Carboniferous. The well Düste Z9 explored the formation at a different location of the reservoir. A total of five hydraulic fracture treatments were carried out across different sands. Due to a variety of geological and technical reasons, production performance was sub-optimal and the well had to be shut-in after a few years.

The subsurface target of Düste Z10 was chosen based on a structural high of the Carboniferous and the proximity to Düste Z9 to benefit from near offset geological data. The project planning process incorporated lessons learned from offset wells and the latest developments in tight gas production technology including data acquisition along with well and hydraulic fracturing designs. Düste Z10 was planned as a vertical well to determine the lowest gas bearing sand and gas-water contact and to provide the maximum flexibility for hydraulic fracture design.

The subsurface target coordinates determined the general area of the surface well site location. The detailed selection of the well site took into account the legally required minimum distances to communi-

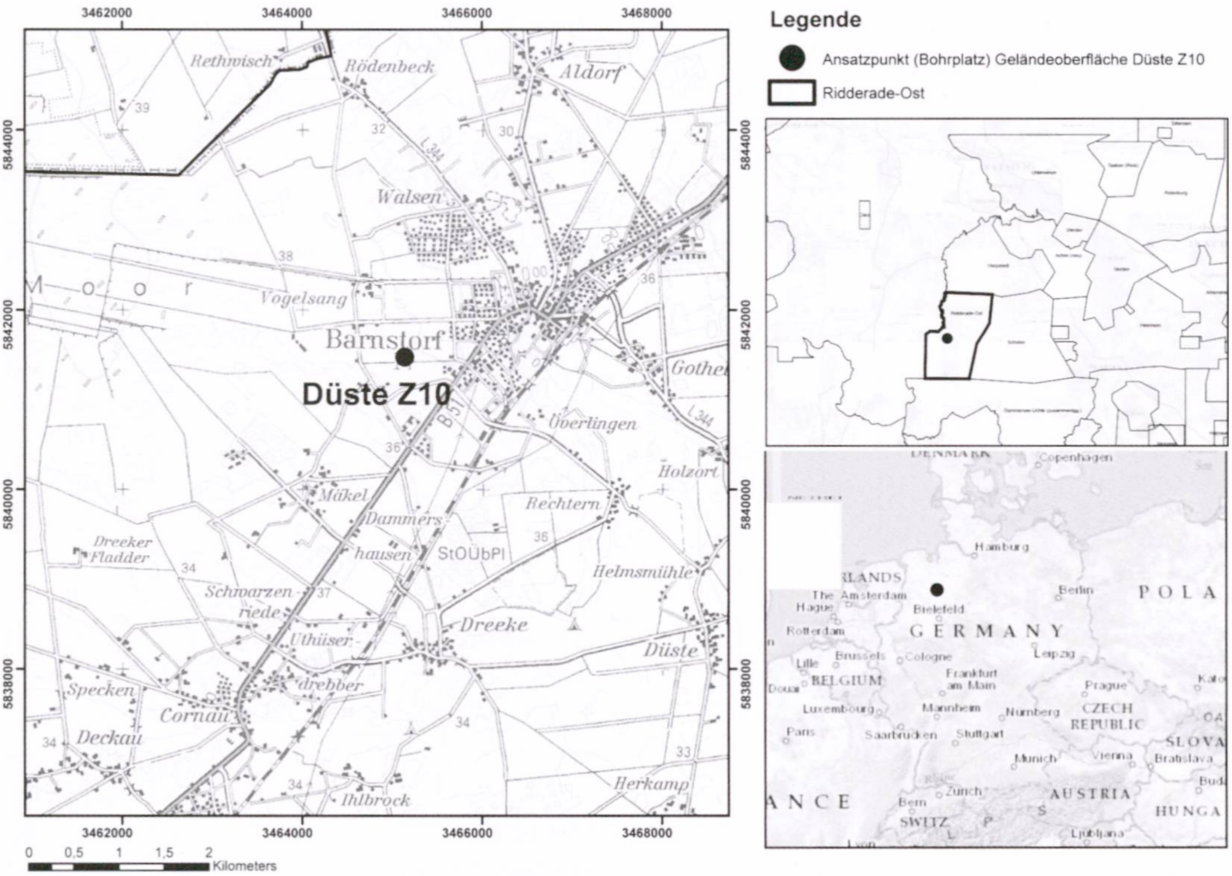

Fig. 1: Düste Z10 well location in production license Ridderade-Ost.

ties, single houses, infrastructure and environmental protection areas. The technical and economical reach to subsurface target coordinates as well as the requirements for surface space for further wells (cluster drilling) including a gas dehydration facility also had to be balanced.

3 Permitting

Wintershall commenced the Düste Z10 project in early 2011, when hydraulic fracture treatments were still permitted and carried out in Germany. However, at that time, the subject of hydraulic fracturing just started to be viewed critically by the German public. Therefore, Wintershall planned the execution of the project to be closely accompanied by a stakeholder engagement strategy, which called for early and complete involvement of all relevant authorities, local politicians, the public and immediate neighbors. Prior to any official permit applications the contents were presented to and discussed with relevant authorities and local politicians. Multiple public events with more than 1.000 visitors complemented the strategy in the community adjacent to the operation. Wintershall also created a special internet site for German operations, closely informing the public on the progress at the Düste Z10 project.

Due to the increased public perception of hydraulic fracturing, the Mining Authority required application for a General Permit («Rahmenbetriebsplanantrag») for the entire project, which is possible under the existing mining law. In the past, General Permits were only mandatory for large facilities but not for single wells, even if hydraulically fractured.

This General Permit required broad technical descriptions of the different operational stages:

1. Site construction;
2. Drilling and completion operations including water usage;
3. Hydraulic fracturing and well test operations.

In addition an Environmental Impact Assessment Study of the planned operations had to be performed by a third-party.

The General Permit application, as opposed to a normal permit application («Sonderbetriebsplanantrag») is distributed for endorsement to other relevant authorities, most importantly to the Water and Environmental Protection Authority of the county. Therefore these authorities were formally included into the permitting process. The Düste Z10 General Permit was approved in summer 2011.

As per the mining law, Wintershall also applied for separate permits for each of the different operational stages. These permit applications included detailed technical descriptions of the planned operations. The applications for construction of the well site and drilling and completion operations were both submitted to the Mining Authority in summer and fall 2011 respectively and subsequently granted. The well site was constructed in fall 2011 and drilling and completion operations were carried out from January to beginning of May 2012.

The last hydraulic fracturing operations in Lower Saxony were permitted in summer 2011. Thereafter, the Mining Authority did not process any new permit applications. At the beginning of 2012 the authority issued a new directive on structure and minimum content requirements for new hydraulic fracturing permit applications, which was made a prerequisite for the acceptance of new applications. Wintershall applied for the permit in July 2012, with detailed descriptions of:

- Hydraulic fracturing operations;
- Composition of frac fluid and additives;
- Well site selection and construction;
- Well and completion design;
- Well test operations;
- Barrier formations above reservoir formation;
- Hydrogeological situation in the influence area of well site;

- Environmental impact assessment of the operations.

The Mining Authority accepted the Frac Permit application (incl. well test operations) as submitted by Wintershall. After additional questions were answered to satisfaction, the Mining and local Water Authorities technically approved the Frac Permit early 2013. However, the final approval was blocked at the political level in Lower Saxony (which had undergone a change of government in 2013), arguing that more public participation is required in the approval process. Full approval of the frac permit is therefore outstanding. A new regulation, specifically governing hydraulic fracturing operations has been drafted, but not been enacted yet.

4 Technical Work

4.1 Geophysical Analysis and Geological Modeling

During the planning stage of Düste Z10, data from an existing 3D seismic survey from 1985 was reprocessed. The new data resulted in a qualitative better characterization of the reservoir and was used to build a new static geological model. Three offset wells, two from within the production license and one from outside were used for calibration. The target coordinates for Düste Z10 were determined based on the structural high, preferable reservoir characteristics and relative proximity to the target coordinates of Düste Z9.

4.2 Well Design

The Düste Z10 well design has been optimized for hydraulic fracturing operations. Geophysical and geological data, offset

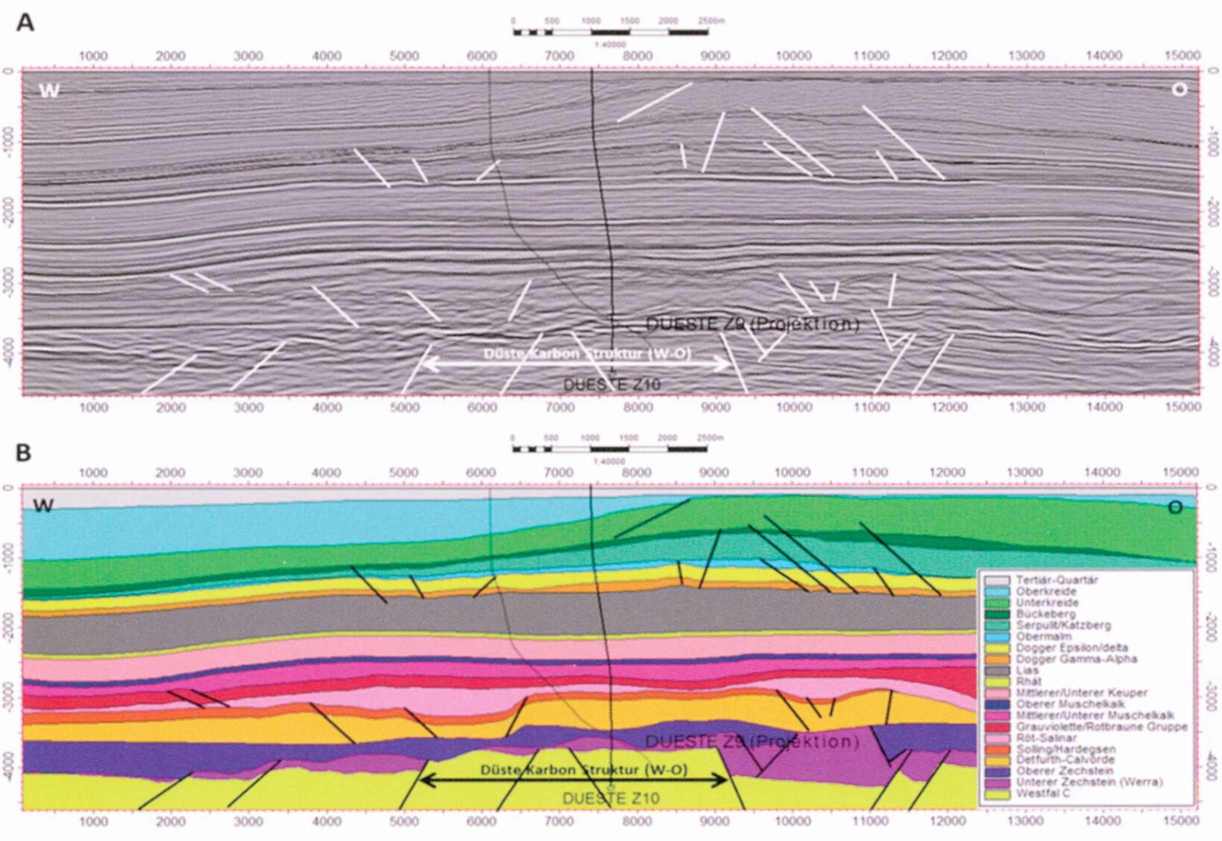

Fig. 2: Seismic X-Section with Düste Z9 and Z10.

drilling and production data, especially from Düste Z9 and other wells in the area served as the main input with respect to general casing design and corrosion aspects. Latest hydraulic fracturing parameters (mainly pumping rates and pressures) as applied in offset wells and comparable settings around the world defined minimum well design parameters, which in practice were inner diameters, pressure ratings and material strengths of production liner, production tubing, completion components, tubing head and X-mas tree.

The intermediate liner and casing sizes had to be designed around these minimum design requirements. Selected tubulars and components have to withstand all major load cases that are possible throughout the life of the well. These are simulated with standard well and completion design software programs. Generally, the most severe load cases throughout the life of the well include pressure tests, early life production and shut-in scenarios, late life production scenarios and fluid injection scenarios.

Hydraulic fracturing, for example, repre-

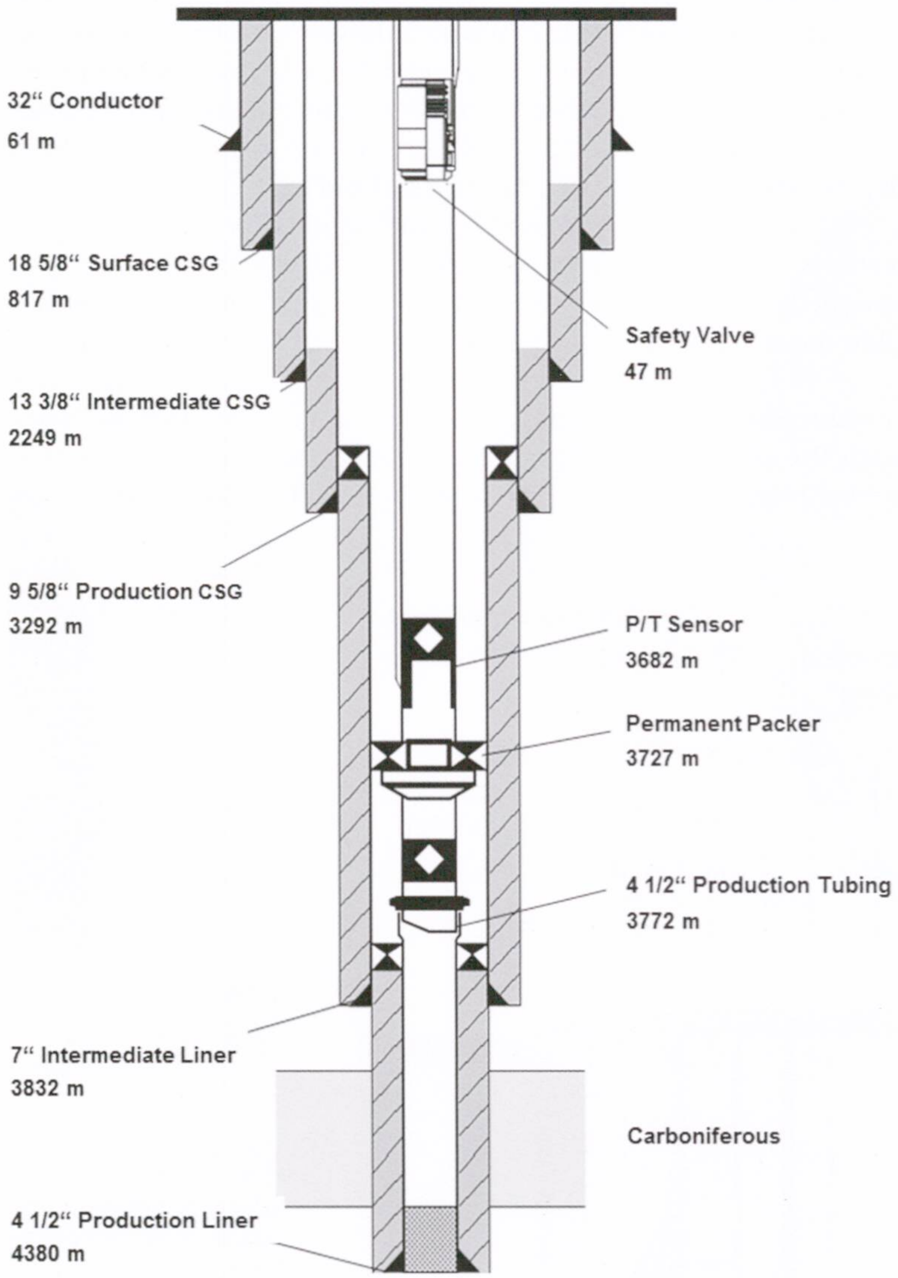

Fig. 3: Well design Düste Z10.

sents a fluid injection case. The simulator takes into account induced temperature and pressure changes and simulates corresponding material forces and stresses, which have to stay within 80% of the material specific maximum yield strengths. The well design process is iterative and ends when suitable size and material combinations are found for the entire well.
A permanent down-hole pressure and temperature gauge was selected for the production tubing close to reservoir depth to allow real-time pressure and temperature control during the hydraulic fracturing treatments and long-term reservoir monitoring. A permanent packer is required at the bottom of the completion string. It creates an annulus between production casing and production tubing (annulus #1, see Fig. 4). This annulus is needed for well integrity monitoring and pressure support, for example during hydraulic fracturing operations. Anchoring the tubing with a permanent production packer is part of the double barrier principle.
All fluids injected into or produced from the reservoir are forced through the inner production tubing and production liner. The fluids cannot get into contact with the production casing or any other parts of the well. The production tubing can therefore be viewed as a «wear part», which could be replaced any time in case of an integrity issue. The Düste Z10 well design foresees five concentric tubulars across the depth interval of the fresh water aquifer (0-50 m) providing total protection from inner well fluids (Fig. 4).

4.3 Site Construction

In Germany, drilling sites are constructed according to guidelines as set out by the WEG (Wirtschaftsverband Erdöl- und Erdgasgewinnung e. V.), which are some of the most stringent worldwide. All surface areas of the well site, which may get in contact with fluids used during drilling, hydraulic stimulation and production tests, must be built «leak tight» (WEG 2006).
Prior to well site construction for Düste Z10, the conductor pipe was driven to a depth of more than 60 m, protecting the fresh water aquifer (0-50 m) from future drilling work (Figs. 3 and 4). Only afterwards construction of the roughly 10.000 m^2 large site com-

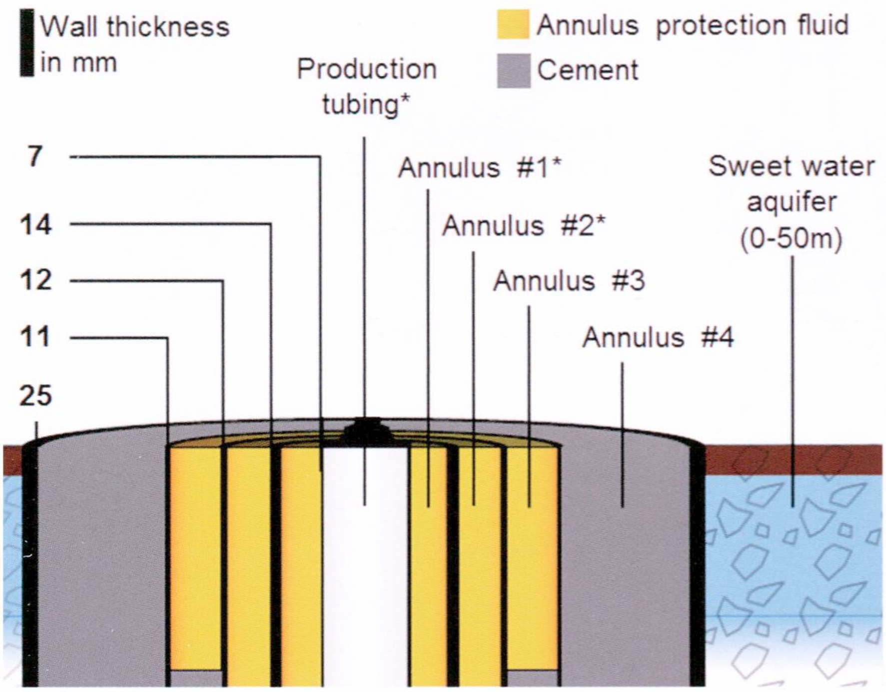

Fig. 4: Düste Z10 design across fresh water aquifer; [*] permanently pressure and temperature controlled.

menced, which was sealed against the conductor pipe. The inner area is equipped with a surrounding fluid barrier and an independent drainage system to a double hulled tank. The outer area is equipped likewise.
In order to take baseline analyses and perform long term monitoring of the fresh water aquifer in the proximity of the well site, three water wells were constructed. Data taken from these wells was also used for the hydrogeological expertise, which was a required input for the frac permit application.

4.4 Drilling and Completion

The drilling rig was mobilized to the well site in December 2011. After drilling to the first casing section depth, the surface casing was run and cemented to surface. The cement quality was independently checked by wire logging methods and pressure tests before drilling of the next section commenced. Each following casing and later the liners were checked for cement quality and pressure integrity in the same manner.
Each well section was logged before (open-hole logging) and after casing and cementing it off (cased-hole logging). Most of the measurements run in the upper hole-sections were standard logs for stratigraphic description and determination of cement and casing quality. Standard mud logging was performed during the entire drilling operations at shortened intervals across the reservoir section. In the target formation, several cores were taken to be able to carry out routine and special core analysis. This data was used to calibrate the following well logging measurements and provided geologists with actual reservoir rock samples for improved geological modelling.
A specially tailored logging program was carried out in the reservoir section to allow for thorough tight gas reservoir characterization and hydraulic fracturing design. Additionally, a special VSP (Vertical Seismic Profile) log was run to be able to accurately tie Düste Z10 into the existing 3D seismic survey. Cased logging finally confirmed cement quality and provided a baseline measurement for later planned log based frac-height determination.
Before running of the well completion, the well was pressure tested to maximum anticipated annulus pressures during the

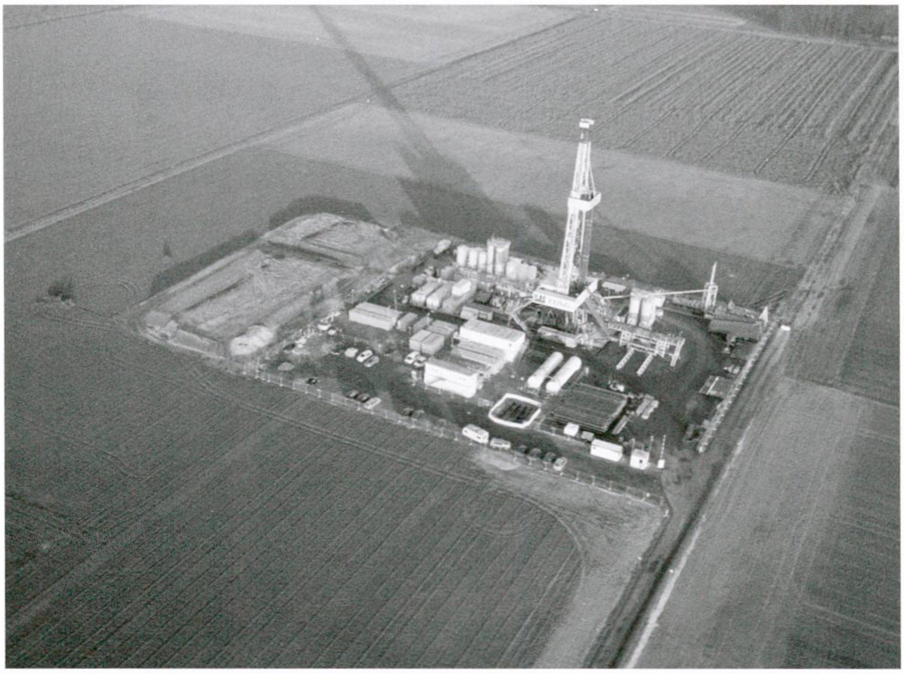

Fig. 5: Drilling rig on Düste Z10.

hydraulic fracturing process. Afterwards an inflow test confirmed pressure containment from the reservoir. Afterwards the well completion components including the down-hole pressure and temperature sensor and permanent packer were installed such to ensure mechanical continuity to the production liner (mono-bore concept, Fig. 3). Following X-mas tree installation, pressure tests confirmed pressure integrity and readiness of the entire well construction for the hydraulic fracturing operations.
After demobilization of the drilling rig, the wellhead was equipped with pressure and temperature sensors on the tubing head and on annulus #1(between production tubing and production casing) and annulus #2 (between production casing and intermediate casing). These sensors together with the permanent down-hole pressure and temperature sensor on the production tubing were connected to the distributed control system providing a means for continuous pressure integrity monitoring of the well (see Fig 4). This system will be used for real-time monitoring of well integrity during the frac operations and for long term monitoring of reservoir and well performance.

4.5 Frac Design

The hydraulic fracturing design was carried out in different stages. Before Düste Z10 was drilled, a general design was drafted based on data from offset wells, namely Düste Z9. This data included stratigraphy, pore pressures, rock mechanics, local stress field and job data from the five hydraulic fractures pumped in 1995. The fracture orientation in this area is well known from offset data from several wells. Fractures in the Düste Reservoir at this depth develop vertically along the maximum horizontal stress direction, which is roughly North-Northwest – South-Southeast.
As new data became available from Düste Z10 (logging data, core measurements, actual well orientation, geometry and design), a detailed frac design was carried out as per the actual stratigraphy in the reservoir. It specifically determined the number of required frac treatments, perforation design, frac treatment sizes per gas bearing sand, fluid types and resulting formulations, fluid volumes, proppant types and volumes, pump rates and pressures.
Wintershall carried out special regained conductivity tests to determine optimal fracturing fluid formulations using chosen proppants under in situ conditions (reservoir pressure and temperature). This involved optimization of polymer-breaker and high-temperature stabilization concentrations in the fluid.
Generally, no single concentrated frac fluid additive of the planned fluid formulation rates higher than water hazard class 1 (WHC 1 = low hazard to water) according to the VwVwS (Verwaltungsvorschrift wassergefährdende Stoffe). For example, the fluid which forms on streets during winter, when sodium chloride is used as the de-icing agent, already is classified WHC 1. In the frac fluid the additives are highly diluted. In the Düste Z10 frac fluid formulation, water and proppants (both not WHC rated) make up 99.2% and additives only 0.8% (max. WHC 1 rated) of the frac fluid. Nevertheless, since the additives are rated WHC 1, the frac fluid mixture in total automatically rates WHC 1.

4.6 Frac Operations (Outstanding)

The detailed frac design determined the necessity of seven frac treatments for Düste Z10. These were planned to be conducted over a two-month period, averaging about one frac treatment per week including mobilization, all required auxiliary operations, well clean-up and demobilization.
There is no risk of fracturing fluid unintentionally leaking into the fresh water aquifer during these operations. The following theoretical leak paths were examined and discussed:

- Surface leakage at the well site;

- Lateral leakage through the well;
- Vertical leakage up along the outside of the wellbore;
- Vertical leakage up through the formations from the reservoir.

Surface leakage of fracturing fluid during operations are highly unlikely, since fracturing fluid is not stored at the location, but only mixed «on-the-fly» immediately before being pumped into the well. The entire fracturing equipment is located within the leak tight inner area of the well site. Only municipal water is stored in tanks before the operation starts. A frac fluid additive truck trailer contains all required liquid additives, which are stored according to the double barrier principle. It has to be noted that even the concentrated frac additives are within the WHC 1 rating. In the unlikely case of leaking surface equipment downstream of the mixing equipment, a maximum of about 2 m^3 of frac fluid (incl. additives) could reach the leak tight inner surface area of the well site without control systems and operator personnel taking notice of it. The 10 cm high fluid barrier around the inner area has a fluid containment capacity of 200 m^3 with an independent 100 m^3 double hulled tank connected to the drainage system. Therefore it is impossible for the frac fluid mixture to leak into the fresh water aquifer. Additionally, as confirmed by the findings of an independent hydrogeological specialist, the fresh water aquifer in the area of the well site is naturally protected by 8–15 m thick natural clays. This type of hydrogeological setting is e.g. a prerequisite for the construction of municipal garbage disposal dumps in the state of Lower Saxony in order to protect the fresh water aquifer.

Lateral leakage of fracturing fluids through the well is technically impossible. As described above, production tubing, annuli #1 and #2 pressures are constantly monitored. In case of a pressure integrity issue, hydraulic fracturing operations would not be carried out. A pressure integrity issue

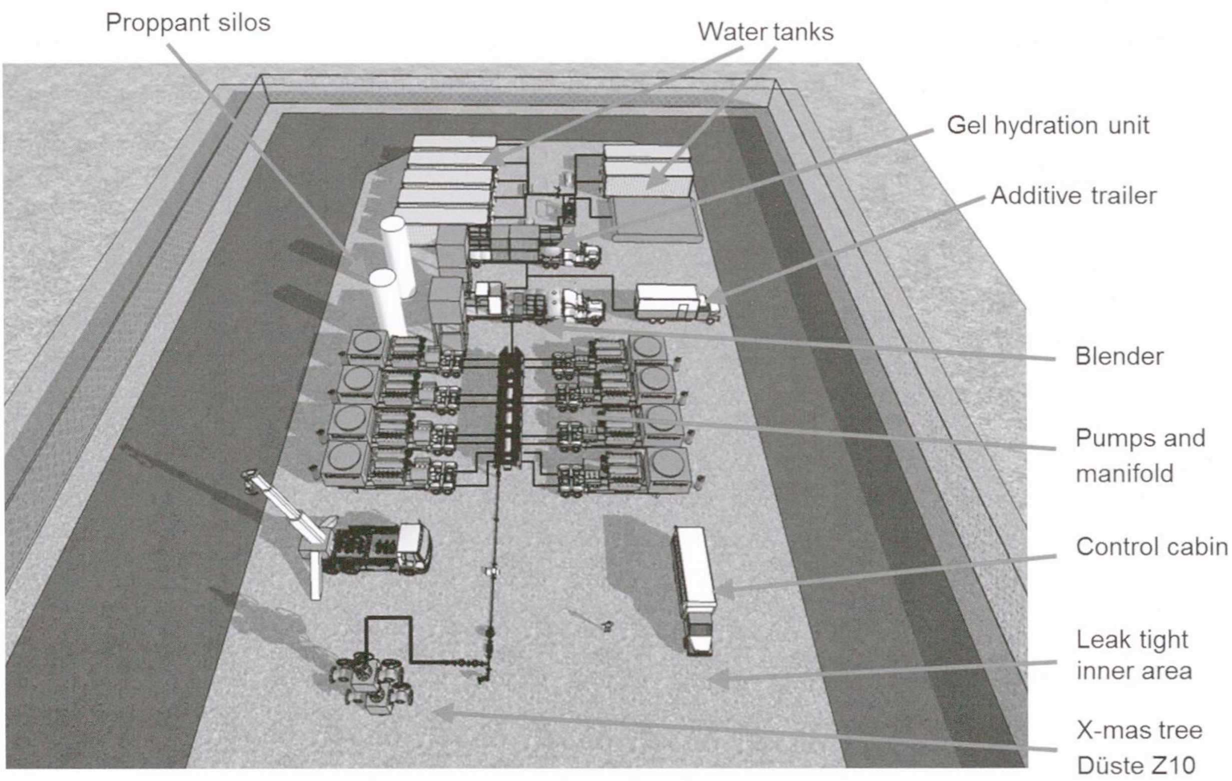

Fig. 6: Layout of fracturing equipment in inner area of Düste Z10 well site.

during fracturing operations would instantaneously lead to opening of a pressure relief valve and to pump shut down. Since a total of five steel barriers exist, there is no direct leak path of the fracturing fluid from the production tubing to the fresh water aquifer (Fig. 4).

Vertical leakage from fractures created in the reservoir at more than 3.800 m depth up along the outside of the well is impossible as two (Zechstein- and Muschelkalksalinar) several hundred meters thick salt formations are located above the reservoir. Special thick-walled casings had to be set across these salt formations in order to keep the salt from deforming the casings, as it is mobile under the existing pressures and temperatures. Salt formations are therefore «self-healing» and often provide the main barrier above hydrocarbon reservoirs in Northern Germany.

Vertical migration of fluids from the reser-

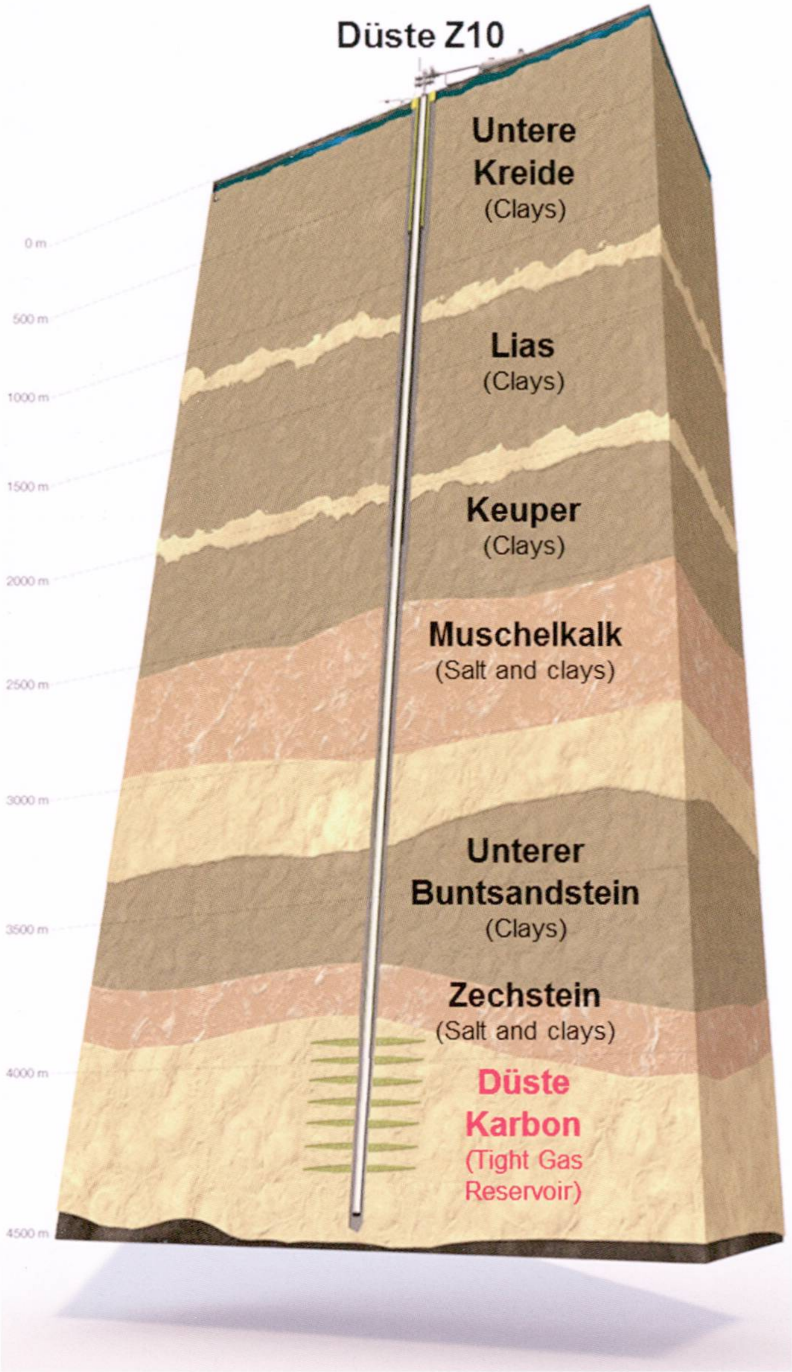

Fig. 7: Salt and clay barriers above Düste Carboniferous tight gas reservoir.

voir across more than 3.800 m of various impermeable barrier formations into the fresh water aquifer is impossible. Next to the salt formations, several thousand meters of impermeable clay formations exist. Additionally, hydraulic fracs, designed for the Düste tight-gas reservoir, ideally will reach half lengths of up to 150 m and heights up to 100 m but normally less as they are constrained by shale barriers within the reservoir.

The larger the frac, the more reservoir rock is exposed, into which frac fluid leaks off. Therefore there is a maximum frac size which can be reached, which is defined by the balance of fluid leak-off and maximum fluid pump rate, which is constrained by maximum allowable pressures. Additionally there are rock mechanical-, stress field-, lamination- and fluid-related effects impacting the maximum size of hydraulic fracs just to name a few.

Conductive faults across the barrier formations above the reservoir do not exist. If they would exist and they would be conductive, the target gas reservoir would not exist. Moreover, frac fluids are heavier than hydrocarbons, i.e. if hydrocarbons do not migrate up from the reservoir (in this case the target reservoir would not exist) water will also not migrate up against gravity.

During the frac-operations in the Düste Z10 well, which only last 1-2 hours per treatment, control systems and operations personnel monitor all relevant pressures and volumes constantly. If any abnormal pressures or volumes are observed, the pumps are immediately shut down.

For Düste Z10 it was additionally planned to carry out micro seismic monitoring of the created fracture geometries. The offset well Düste Z9, which is only about 500 m away at reservoir depth, was specifically prepared for placing geophone receivers. Also, it was planned to use special proppants in some of the treatments to be able to carry out fracture height logging at the wellbore. These measurements were only intended to improve the accuracy of the simulation models in the order of 10s of meters for future frac operations.

The operations are not expected to induce any seismicity at the surface that can be felt by humans or cause damage to buildings ($M_L > 2.5$). During several recent hydraulic fracturing treatments of the same formation in a near offset well no induced seismicity at the surface has been measured by the German Regional Seismic Network (operated by the Bundesanstalt für Geowissenschaften und Rohstoffe).

A long-term production test was planned following the completion of hydraulic fracturing operations. One of Wintershall's own well test equipment packages will be utilized for this test and installed within the inner area of the well site. The pipeline tie-in to an existing raw gas production gathering system was already constructed as part of the well site preparation. Part of the hydraulic fracturing treatment fluids will be produced back with the gas and reservoir water. The fluids will be separated by the well test equipment and temporarily stored at the well site in closed tanks. Safe fluid disposal will either be organized by approved specialized companies or injected into approved disposal wells within depleted oil and gas reservoirs.

5 Conclusions and Outlook

Hydraulic fracturing operations have been applied in Germany more than 300 times since 1961 without any harm to the environment. The strict regulatory framework has ensured that operations are carried out consistently to high safety standards. Moreover, in light of the critical perception of the technology, the German oil and gas industry has developed a catalogue of best practices that is also publically accessible (WEG 2014).

The Düste Z10 Tight Gas Project in Lower Saxony has been planned, permitted and executed in accordance with these best practices, key elements of which are:

1. Evidence of effective geological barriers above the reservoir;
2. Prevention of surface spill risk by adequate well site construction;
3. Prevention of subsurface spill risk by adequate well design;
4. Full understanding and control of created frac dimensions;
5. Safe disposal of produced fluids after hydraulic fracturing operations;
6. Prevention of damaging induced seismicity at the surface.

However, the hydraulic fracturing permit for Düste Z10, despite the fact of being technically approved, was blocked at the political level in early 2013. The project is therefore on hold since that time.
In 2014, the state of Lower Saxony drafted a new regulation concerning the approval process of hydraulic fracturing, which distinguishes between operations in conventional reservoirs (including tight gas) and operations in unconventional reservoirs (Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2014). Generally, environmental impact assessments will become mandatory for all hydraulic fracturing operations and have to be made publically available including permitting documentation. The new regulation mainly aims at providing a solid legal foundation for more public involvement. However, this new regulation has not yet been enacted by Lower Saxony. In parallel, Germany is working at the national level to adapt the existing legal framework to the new public perception.
In the summer of 2014, the first hydraulic fracturing operation since three years has been approved and executed in Germany in the state of Mecklenburg-Western Pomerania. Assuming that the new regulation will be enacted in Lower Saxony by the end of 2014 and taking into account all statutory periods, work on Düste Z10 realistically might only resume in early 2016.

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