Chapter 2
Technical Aspects of CO_2 Injection

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Abstract The almost depleted Altmark gas field was chosen by the owner and operator GDF SUEZ E&P Deutschland GmbH (GDF SUEZ) for an Enhanced Gas Recovery (EGR) project. GDF SUEZ took part in the joint research project CLEAN providing this site as a basis for the scientific work of the partners from academia and industry. In November 2007, GDF SUEZ filed the application for injection of up to 100,000 t of CO_2 with the State Office for Geology and Mining of Saxony Anhalt. The permitting process came to a halt towards the end of 2008, because the responsible mining authority considered a national CCS (Carbon Capture and Storage) law to be the only legal basis for approval. The national CCS law still has not been enacted in Germany. In January 2009, the erection of the interim CO_2 storage and conditioning unit in Maxdorf was completed. New flow lines between the Maxdorf and the potential injection wells were fully planned but never build. Corrosion resistant re-completion of the injection wells did not take place either. Within the funding period of the CLEAN project (2008–2011), there was no injection of CO_2.

The Altmark natural gas field located in the federal state of Saxony-Anhalt (Fig. 2.1), owned and operated by GDF SUEZ E&P Deutschland GmbH (GDF SUEZ) is known as the second largest gas field in onshore Europe (area of ca. 1,000 km^2). Production started in 1969 and reached top peak production in the mid 1980th with approximately 12 billion cubic metres per year (Fig. 2.2). Today, after production of approximately 265 billion cubic metres gas, the field is in its tail end phase (average recovery of total gas in place is 80 %) with an annual production of some 500 million cubic metres. Due to the gas production, the initial reservoir pressure is reduced from initially 42.5 MPa to approximately 8.5 MPa.

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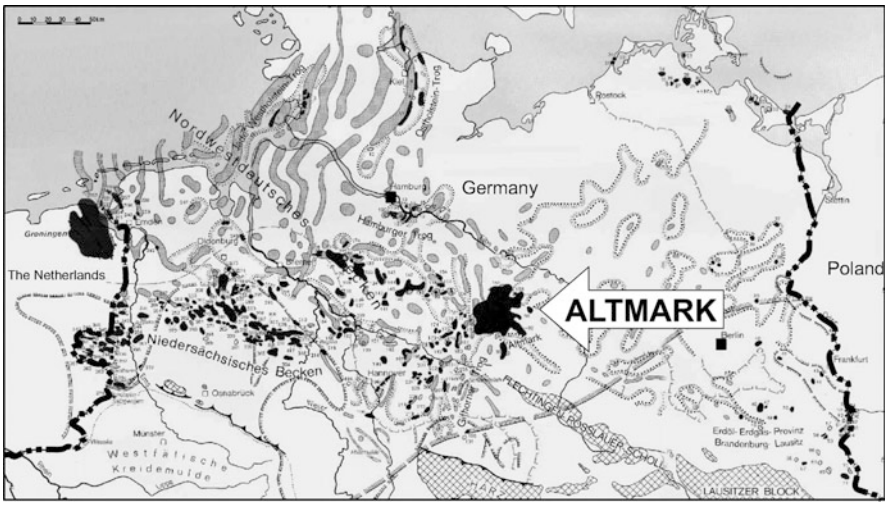

Fig. 2.1 Location of the Altmark natural gas field. Gas fields (*dark grey*), oil fields (*grey*) and underground saline structures (*light grey*) (Source: LBEG Lower Saxony)

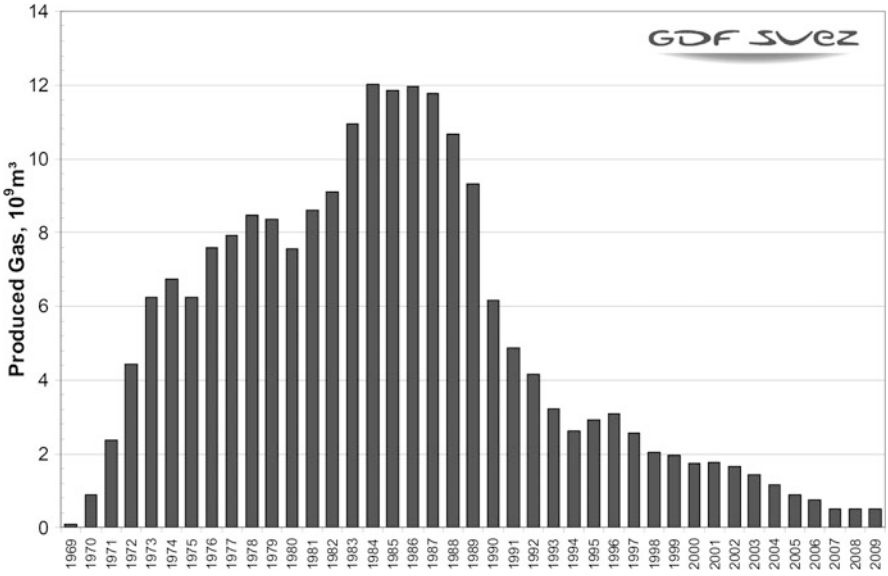

Fig. 2.2 Annual production of natural gas from the Altmark field between 1969 and 2009 (in billion cubic metres)

In Germany, research activities dedicated to CO_2 storage as potential means to mitigate climate change started more than 10 years ago at the Federal Institute for Geosciences and Natural Resources (BGR) and the GFZ – German Research Centre

Fig. 2.3 The interim-storage and conditioning unit near Maxdorf (Altmark). In the very front of the two 300 m^3 vessels, two injection pumps are installed. Four air cooled evaporators can be seen to the *left hand side*

for Geosciences. Besides saline aquifers in the North German Basin (Gerling et al. 2009), the Altmark, as the only almost depleted giant onshore gas field with an assumed storage potential of approximately 500 million tons of CO_2 (May et al. 2003), attracted attention from researchers as well as the power generating industry.

In this context and with regard to further utilisation of the Altmark gas reservoir, GDF SUEZ was approached by several industry partners since 2003. In 2006, GDF SUEZ started conceptual arrangements towards a future pilot project to be conducted in the structurally and hydraulically isolated subfield Altensalzwedel, which is representative for the entire Altmark field, with regard to the reservoir properties and infrastructure in place. In September 2007, GDF SUEZ and Vattenfall Europe (VE) agreed to commission the pilot project for Enhanced Gas Recovery (EGR) in cooperation.

During preparation of the project, the Federal Ministry of Education and Research (BMBF) invited GDF SUEZ to take part in the national joint research project CLEAN. Therefore, in November 2007, GDF SUEZ commenced the application procedure for the EGR pilot project to receive permission for CO_2 injection from the mining authority in Saxony-Anhalt, the State Office for Geology and Mining, under the given mining law. The application covered the installation and commissioning of surface facilities (Fig. 2.3) for taking-over and conditioning the

CO_2 provided by VE via trucks from the Schwarze Pumpe pilot power plant southeast of Berlin. In addition, the relaying of appropriate flow lines and recompletion of wells chosen for CO_2 injection were key activities proposed. In March 2008, the CLEAN project was approved by the BMBF and started in the following July. In January 2009, the CO_2 storage and conditioning unit in Maxdorf was erected. However, by the end of 2008, the approval process came to an unexpected halt. Despite the fact that the application was filed under mining law in the first instance, the mining authority considered a national CCS (Carbon Capture and Storage) law to be the only legal basis to approve the injection permission from that time on (per October 2011, the national CCS law still has not been enacted).

Injection of up to 100,000 t of CO_2 in the framework of the EGR pilot project was supposed to provide the technical basis for the joint R&D project CLEAN. Aim was to test, evaluate and approve the general capability of the Altmark reservoirs for EGR and CO_2 storage as well as to demonstrate the technical capability to condition and inject CO_2 into Altmark Rotliegend reservoir. Further, it was planned to elaborate and evaluate future opportunities for an economically attractive utilization of the gas field.

The following steps were planned to be tested:

- Take-over of liquid CO_2 transported by trucks from the pilot plant Schwarze Pumpe to the Altmark;
- Interim storage of CO_2 in two 300 m^3 vessels at pressure and temperature of 1.5 MPa and 27 °C, respectively;
- Conditioning of CO_2 in order to test different aggregate states and to run different injection regimes with regard to volumes and rates, including the optimisation of the entire process with regard to energy consumption;
- Routing the CO_2 to the two injection wells at a maximum pressure of 9.0 MPa in a temperature range from +8 °C up to +40 °C;
- Injection of CO_2 into the Rotliegend reservoir (depth >3,000 m, temperature ca. 120 °C) and thereby testing the well performance.

Technical specifications of the CO_2 infrastructure comprising the conditioning unit at Maxdorf, the flow lines to the bore holes and the injection wells in the field were planned to be or even built as described in the following sections.

The CO_2 storage and conditioning unit at Maxdorf consisted of:

- Two unloading stations for the trucks;
- Two vessels of 300 m^3 volume each, to store the liquid CO_2;
- Two pairs of air cooled evaporators to be used during CO_2 injection for keeping constant pressure on the vessels by vaporization of liquid CO_2;
- Two booster pumps;
- Two high pressure pumps;
- A pre-heating system allowing for different flow regimes;
- A condensing unit to catch the boil off gas from the vessels and to pump the liquid CO_2 back into the vessels;
- A manifold for four flow line connections.

For transportation of the CO_2 from the conditioning unit in Maxdorf to the potential injection wells, flow lines were planned but not built:

- Two new flow lines (6 in. nominal diameter) were thought to be linked and connected to the potential injection wells with pipelines of 770 and 3,380 m length, respectively;
- The chosen material for the flow lines was stainless steel (ferritic-austenitic) AF-22 in order to be able to maintain the conditions required for liquid-, gaseous- or supercritical CO_2;
- Pipelines were planned to be equipped with cathodic corrosion protection.

For the purpose of CO_2 injection the potential two wells would have required a re-completion to build in corrosion resistant materials. For well heads and tubings it was planned to use Cr^{13}-steel.

Within the funding period of the CLEAN project between July 2008 and December 2011, there was no injection of CO_2. However, despite this setback for the CLEAN project, it was possible to complete most of the work although some adjustments to the implementation and the objectives were necessary.

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