Abstract

Carbon Capture Utilization and Storage (CCUS) is a promising technology for the reduction of CO₂ emissions, e.g. from fossil-fuel operated power plants, steel and cement mills or refineries. Crucial points for a sustainable and future-proof CCUS procedure are reliability and cost efficiency of the pipeline transport network, particularly concerning corrosion risks under varying amounts of impurities and moisture in the CO₂ stream. Recent studies have shown that even high alloyed steels might be susceptible to general and/or localized corrosion caused by condensates[1,2].

In the context of CLUSTER project[3] – German acronym for impacts of impurities in CO₂ streams captured from different sources in a regional cluster on transport, injection and storage – studies on corrosion mechanism of oxidizing, reductive and mixed atmospheres towards transport pipeline steel were carried out. Due to the absence of certified benchmarks for upper limits, systematic experiments, based on thermodynamic calculations, with impurities in the CO₂ stream were performed. In this study, SO₂, NO₂ and O₂ acted as corrosive components for oxidation processes (Oxyfuel, Post-combustion), while H₂S and H₂ for reductive atmosphere (Pre-combustion) were applied[4]. The employed moisture content in all experiments was 50 ppm_v[5].

The experimental setting consists of two units, a gas supply system, providing the experiment with up to 9 different gases simultaneously, and a high pressure reactor, equipped with a load frame for simulating stress cracking conditions on the pipeline wall[6]. The experiments were operated in a circulation flow system using a pressure of 10 MPa and a temperature range of 278 K ≤ T ≤ 313 K, according to the ambient temperature[7] for terrestrial or subterranean pipelines. To determine the corrosion rate the experiments were performed in a time scale of 100 h, 300 h and 1000 h. Based on results of previous work[4] X70 (1.8977), a ferritic-perlitic carbon steel, was selected and specimens were ground. Characterization of corrosion products was carried out by optical microscopy, WLI, (GI)XRD, SEM/EDX and FIB.

Due to the applied moisture to the stream, in combination with the impurities an acidic atmosphere in the experiments was generated. However, no acid condensation could be detected, attributed to the low moisture content of 50 ppm_v. Comparing specimens braced by the load frame with unstrained ones leads to the conclusion that there is no influence by tensile stress (up to 50 Nm/mm²) towards layer formation or cracking, regardless of the employed gas atmosphere or the temperature. However, a high impact for the corrosion behavior in the high pressure experiments had the factor temperature. It revealed clearly, the lower the temperature the higher the corrosion rate.
Due to the used impurities in the experiments the strongest corrosion occurred in mixed atmosphere, employing oxidizing and reductive components, closely followed by streams with pure oxidizing character. By far the lowest corrosion rate (approx. 10 times lower) resulted from reductive atmosphere. In general, at constant temperature and pressure the CO$_2$ stream composition strongly influences the morphology, thickness and composition of the corrosion products. Applying oxidizing or mixed settings, Fe-hydroxides (e.g. goethite or lepidocrite) emerge as dominating corrosion products, able to incorporate up to 7% sulfur by mole fraction under mixed conditions. However, under reductive atmosphere no phase identification (XRD) was possible, caused by the very thin corrosion layer and low crystallinity. Applying SEM/EDX it revealed surprisingly the formation of Fe-O compounds, most likely attributed to the oxygen partial pressure in the system induced by CO$_2$ (≥98.5 % by volume) and the volatile H$_2$O.

In addition to the chemical homogeneously generated corrosion layer, secondary phases had grown locally distributed on top of it. These compounds are characteristic for the applied atmosphere and vary in number, shape and their chemical composition.

To support experimental data investigations by in-situ gas chromatography experiments are being performed to get a deeper understanding of the kinetics of chemical reactions in the stream and the interaction of the applied atmosphere with the surface of the pipeline steel X70.

References