IEAGHG Information Paper: 2016-IP2; 2nd International Forum on Recent Developments of CCS – the impact of impurities on the whole CCS chain from capture to transport and storage

16th – 17th December, 2015, Athens

The 2nd International Forum on Recent Developments of CCS, held between 16th and 17th December in Athens, brought together pan European expertise from SINTEF in Norway, Ruhr-Universität Bochum and BRG from Germany, University of Leeds, Warwick, and Imperial College from the UK, OCAS, from Belgium, the Dutch research institute, TNO, the University of Zaragoza and CIUDEN from Spain, NCSR Demokritos from Greece plus representatives from USA, China and IEAGHG. The two day meeting covered recent research supported by EC 7th Framework under the CO_2QUEST and IMPACTS programmes.

The theme of the meeting was the impact of impurities in CO_2 on transport and storage. There were a series of presentations on the thermodynamic properties of CO_2 with varying levels of impurities which clearly highlighted that small amounts of impurities can have a big impact on operational conditions. The gases of interest include N_2, O_2, Ar, CH_4, H_2O, CO, H_2, SO_2. The composition of impurities, and their concentration, can influence viscosity and pressure which are key parameters for the design and operation of pipelines. Much of the research under the IMPACTS Programme has focussed on the development of modelling CO_2 mixtures and subsequent verification from experimental data.

The efficacy of CCS as a means to mitigate CO_2 emissions from different industrial sectors depends on the minimisation of the costs associated with purification, compression and transportation of captured CO_2. Removing impurities from a captured CO_2 stream such as N_2, NO_X, SO_X, H_2S, H_2, O_2 and Ar is a costly and energy intensive process. Leaving these impurities in the gas would lower the capture cost, but could have a potentially negative impact on transport and storage compared with CO_2 streams with trace amounts of impurities. The IMPACTS programme has investigated strategies for power requirements and compression of CO_2. The associated costs to an entire project if CO_2 is purified before transport and storage also need to be considered. There may be a trade-off between transporting lower purity streams and implementing corrosion-preventive measures. Multiple factors influence design and costs hence the importance of discovering the relationship between CO_2 stream quality and cost of safe transport and storage.

Fundamental vapour-liquid equilibrium data have been established for CO_2-N_2, CO_2-O_2 and CO_2-Ar mixtures providing improved experimental data. These data can be used to improve the equations of state currently available for these mixtures. Experimental work has determined the effect of supercritical CO_2 mixtures on pipeline corrosion. The results have been used to establish the expected corrosion rate in terms of (mm/year) in pipelines. Impurity levels varied from 1,100 to 3,000 ppm between 40 and 75°C and pressures ranging from 8 to 12 MPa. Based on the results of IMPACT studies, several recommendations for suitable temperature and pressure conditions for multi-stage compression of impure CO_2 streams have been made. Significantly the case for CO_2 streams with less than 5% impurities, multistage compression combined with liquefaction and subsequent pumping from ~62.5 bar, can potentially offer higher efficiency than conventional gas-phase compression.

Seven representative CCS chains have been formulated. These scenarios cover the full range of compositions likely to be encountered in CCS projects over the next 10-25 years. This background material is now ready for use in economic and operational analysis and the risks posed by the effects of impurities. Economic modelling has now started. Different mathematical models for viscoscity have been compared with experimental data for binary mixtures of CO_2 with different impurities.

Comparison of the predictions with experimental decompression data showed that the interpolation method produced robust and highly reliable results for both simple and complex mixtures.

It is well established that the presence of impurities have an impact on many aspects of pipeline design. Two key parameters are the propensity of pipelines to ductile fracture and the release rate from a leak or rupture. The ability to simulate these processes in the presence of impurities is therefore of great value for assessing pipeline safety. A number of projects have included experiments to investigate the behaviour of high pressure CO_2 releases from pipelines to simulate accidental or operational conditions. Typically these are pure supercritical CO_2 releases into air with varying levels of humidity. Data is available in the public domain from the CO_2PIPETRANS, CO_2PIPEHAZ and CO_2QUEST EU funded projects as well as the industry-funded COOLTRANS research programme.

Pipeline specifications have also been tested by conducting fracture propagation tests at different scales including external field-scale tests in the UK and China. A large-scale release and dispersion experiment has now been successfully achieved from an industrial-scale pipeline 258 m in length and an internal diameter of 233 mm. These rupture experiments measured the impact of high pressure releases providing valuable experimental data on the pattern of gas release and rate of fracture propagation. The technique was used to observe atmospheric dispersion of gas clouds. Experimental data derived from a full-scale demonstration test can also be used to successfully validate a proposed design. Three full scale fracture propagation tests have confirmed that fracture arrest will occur in a pipeline and the design, based on experimentation, justifies the optimum cost of pipeline in terms of construction and operation. The refinement of model prediction is also fundamental for design parameters especially safety.

The level of impurities can have implications for operational costs. Two case studies, based on a 500 km pipeline transporting CO_2 with 4% impurities, showed that the transport power consumption in a 24 inch (0.61 m) pipeline can increase by 100%. The most important thermodynamic property is the density. The results also showed an annual cost increase of 8.5% for conditioning and transporting CO_2 with impurities in a pipeline optimised for pure CO_2.

Under the CO_2QUEST programme a series of tests and experiments were conducted to evaluate the effects of impurities on geological storage specifically fluid-rock interactions and leakage. Field injection tests of CO_2 with impurities have been conducted at Heletz in Israel and Catenoy in France. This activity has been complemented with laboratory experiments to determine the impact of impurities on the mechanical properties of reservoir and caprock. Experimental and field data has then been used to verify model projections.

Impurities will affect storage capacity because they displace some of the volume dedicated to CO_2. Capacity deviations can be much larger than the amount of impurities in the CO_2 depending on the depth and level of impurities. The results of storage capacity showed that the capacity of an aquifer at a depth of 800 m decreases by 3.5% compared to a pure CO_2 stream if 5% SO_2 is present. Since SO_2 requires 5% of the pore space volume, the capacity decrease of 3.5% implies a density increase of the impure stream compared to pure CO_2. At greater depth, the storage capacity for the impure stream decreases beyond 5%. At a depth of 3.4 km the capacity decreases by 7%. In addition the presence of 5% SO_2 has significant effects on the geochemical reactions in a sandstone aquifer compared to pure CO_2. This is especially true if the calcium rich plagioclase feldspar anorthite ($CaAl_2Si_2O_8$) is present. The release of calcium under acidic conditions can lead to the form of anhydrite and the subsequent blockage of pores. At lower more realistic SO_2 concentrations of 0.01% to 1%, the simulated porosity decreases are much lower and more similar to the pure CO_2 case. Modelling suggests long term impacts are very limited at low SO_2 concentrations, but cement mineralogy in wellbores can be altered. More research is necessary and field tests are planned.

The meeting has successfully highlighted the significance of impurities across the CCS chain and provided some guidance on the thresholds for impurities in CO_2 streams. IEAGHG has an active and ongoing interest in the impact of impurities. A recent study on flexible operation entitled "Operational Flexibility of CO_2 Transport and Storage", as well as previous research, has investigated the how impurities affect transport and storage.

James Craig
15/02/2016