Guidelines for the Development of Flexible CCS Networks

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Abstract

This paper provides guidelines and best practise for the design of flexibly operating Carbon Capture and Storage (CCS) networks and is based on the findings of the Flexible CCS Network Development project (FleCCSnet), funded by the UK CCS Research Centre. These design and operating guidelines are intended to allow CCS network designers to "future-proof" CCS pipelines in order that they will be able to react effectively to short, medium and long term variations in the availability and flow of CO_2 from capture plants and the constraints imposed on the system by the ability (or otherwise) of CO_2 storage facilities to accept variable flow.

Under normal operating conditions, the flow of CO_2 from a point source (e.g. a power station) is expected to be governed by the load cycle of that source. It is likely that CO_2 capture will run mostly under steady state conditions in early CCS projects, although interruption of the supply of CO_2 could still occur in a controlled manner e.g. during a planned outage, or in an uncontrolled manner e.g. during a plant trip. However, it is likely that, as CCS develops, CO_2 capture will be fitted to plants that are operating more flexibly, leading to variability in CO_2 flow into the CCS transport network e.g. on a daily and/or seasonal basis in response to increased use of intermittent renewables in the electricity system. In addition to the feed-forward from the capture plant, there is also a feed-back into the CO_2 transport network from the geological storage site, which will impose additional variability and constraints on the network through fluctuating injection volumes and potential upset conditions and/or maintenance requirements at the injection point.

The guidelines are based on the findings from this work as well as insights from work published during the project on capture plant flexibility (Sanchez Fernandez et al, 2016 and Lucquiaud et al, 2014). The paper covers the effect of fluctuating and minimum flow rates on different network setups, the line packing capability of dense phase CO_2 pipelines, optimum valve closure and the optimum timing of valve closure and the effect that uncertainties in storage site parameters have on the flexibility of a pipeline network. Key questions answered are:

1. At which conditions of mass flow rate, inlet temperature and reservoir pressure does two phase flow occur in the pipeline?
2. What are the general conditions for operation of a CCS network?
3. What differs when operating the network on a partial load?
4. What happens to the network on applying load changes?

Network development is split into three periods to represent different stages of CO_2 network development (Periods 1, 2 and 3) and the behaviour of the storage site is split into two categories of boundary conditions at the wellhead (Scenarios A and B). Figure 1 shows a schematic representation. Period 1 is a single source to sink pipeline, Period 2 connects two sources to a single sink and Period 3 has multiple sources connected to multiple sinks. Scenario A represents depleted open and closed hydrocarbon fields, while Scenario B represents saline aquifers. In an open reservoir, the average reservoir pressure is hydrostatic and the average pressure in the reservoir remains hydrostatic through the life time of the reservoir. In a closed reservoir, the average pressure is below hydrostatic. Saline formations have some similarities with open hydrocarbon reservoirs; however, there is more uncertainty on the characteristics of the store.

Flexible dense phase CO_2 transportation for Periods 1 and 2 is explored using variable CO_2 flow where the boiler ramp rates control the CO_2 flow. Three types of loadings are considered:

i) Constant
ii) Constant flow rate then ramp down
iii) Ramp up, constant flow rate and then ramp down.

Situations with high renewable energy penetration into the energy mix are anticipated to be most challenging for the pipeline to handle and are illustrated in Figure 2. The major factors to be considered in the design of Period 3 type pipeline networks are discussed. For example, pipeline networks will need to accommodate possible trips within the whole CO_2 chain (e.g. capture by-pass, maintenance or trip at the injection point, etc.) and a wide variety of capture sources and storage sinks.

The amount of available time to store liquid CO_2 is quantified as a function of pipeline size, the inlet mass flow rate, the operating pressure and the slope of terrain. In addition to this, the effect of valve closure time on the instability of the flow is investigated. The line packing time illustrates how much slack a pipeline system can take up.

Constraints imposed on a CCS pipeline network by offshore storage infrastructure are explored through the influence that uncertainties in reservoir performance have on pipeline flexibility. The store is typically a relatively inflexible part of the CCS chain since the possibility of modifying these characteristics to facilitate CO_2 storage is very limited or non-existent. The influence that uncertainty in storage parameters have on the design of the pipeline is discussed and several case studies are developed which are representative of UK storage scenarios.

This work is expected to benefit a broad range of stakeholders and allow network designers to anticipate potential problems associated with the operation of a CCS network. For a cost effective design of the whole CCS infrastructure, all the factors that will have a substantial impact on CO_2 flow will have to be analysed at an early stage to prevent possible bottle necks in the whole chain.

References

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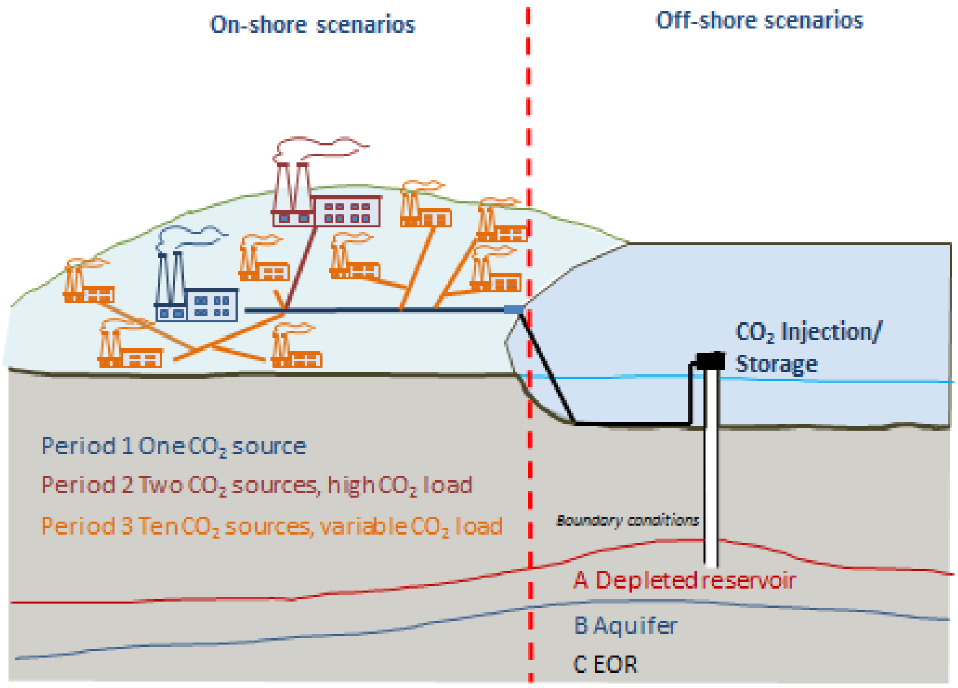

Figure 1: The scenarios considered for FleCCSnet

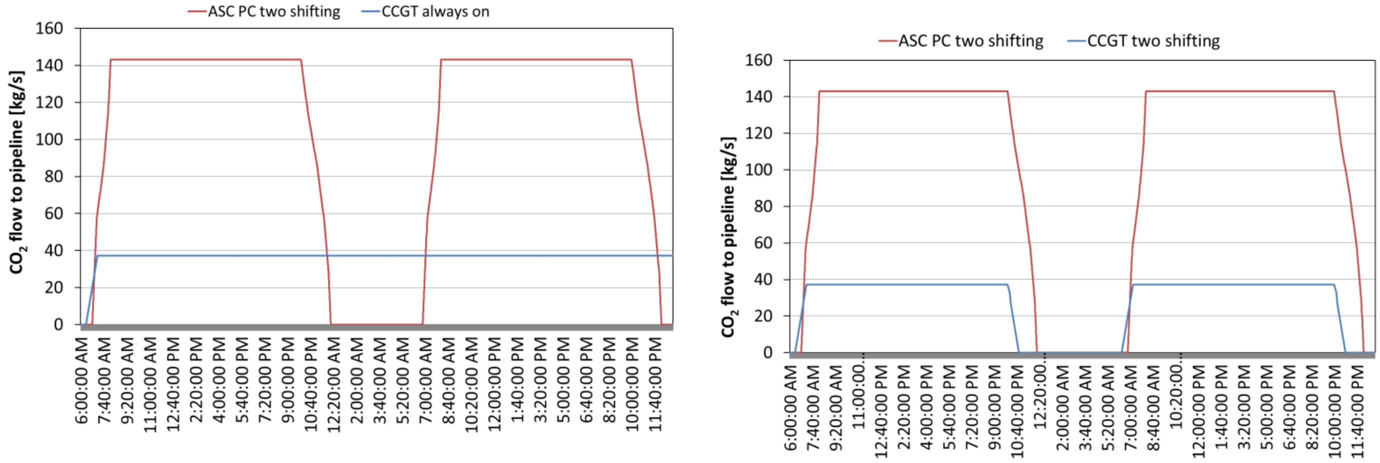

Figure 2: CO$_2$ flow patterns for two power plants for two days with a high electricity demand and low gas price (left) and high net electricity demand (right)