Line-packing capability of CO₂ pipeline transportation networks with variable feed flows

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Abstract
In an effort to reduce greenhouse gas emissions, governments around the world are looking at a range of options to form a basis for a clean, reliable and affordable power generation system. The role and characteristics of different technologies in future low carbon energy systems varies. While nuclear power typically delivers firm and inflexible power, CCS power stations could often deliver firm and flexibly dispatchable power.

While the need for flexible operation of CCS power stations in future energy systems with high penetrations of intermittent renewable power is commonly acknowledged, there is only a relatively small body of literature investigating the issues associated with flexible operation along the CO₂ transportation and storage (T&S) network. Researchers exploring these issues highlight particularly CO₂ injection wells as a potential constraint to large and frequent flow rate changes [1-5]. The issues that are commonly referred to relate to the persistent degradation of injection well integrity, caused by repeated thermal expansion and contraction (and de-bonding) effects due to fluctuating flow rates.

Using line-packing as a way to convert variable feed flows of pipeline transportation networks to relatively steady outflows has been suggested as a way of mitigating the issues related to injection wells. The extent to which dense phase CO₂ pipelines can be used to smooth out flow rate variations is to date, however, unclear.

This paper contributes to the identified gap in the literature by exploring the variability of CO₂ flows feeding into future CO₂ pipeline transportation networks, as well as the extent the networks are able to smooth feed-flows via line-packing, in order to produce steady outflows. The UK energy system is taken as a case study. The study follows a two-step approach:

Firstly, a purpose build unit commitment economic (UCED) dispatch model is deployed to investigate the operating patterns of CCS power stations in future UK low carbon energy system scenarios, building on previous work carried out at the University of Edinburgh [6-8]. High resolution historical weather data is used coupled with historical demand data to maintain the complex interrelationships. Power generation portfolios able to cost-effectively achieve average annual emission intensities of 140g/kWh, 100g/kWh, and 60g/kWh are chosen to reflect UK emission targets. MEA based post-combustion capture technology with a capture rate of 90% is assumed for CCS power plants. CO₂ flow profiles produced by the cost effective dispatch of CCS
generators are analysed and a set of realistic feed flow transients is generated that CO\textsubscript{2} T&S systems will need to be able to handle in the future. Illustrating the strong variability of CO\textsubscript{2} flows feeding into future T&S systems Figure 1 shows for the core investigated scenario (i.e. 30GW installed wind power capacity, 100g/kWh annual average emission intensity) the number of times (in thousands) the net change in CO\textsubscript{2} flow captured collectively by CCS power stations over time periods of 6hrs (rolling basis over the year) reaches certain amplitudes (relative to nominal flow).

Figure 1: Number and relative size of net changes in CO\textsubscript{2} collectively captured by CCS power stations over 6hrs periods (rolling basis) over base year for 15GW (red), 30GW (blue), 45GW (green) wind capacity in 100g/kWh annual average CO\textsubscript{2} emission intensity scenario (medium wind speeds).

Secondly, a number of transportation network designs were selected. Single source to single sink networks were considered along with multiple source and sink networks, for different pipeline lengths and diameters. Building on the previously generated set of CO\textsubscript{2} flow regime scenarios, maximum line-packing times are determined as well as the extent to which flow fluctuations can be reduced by the transportation networks via different line-packing strategies.

The preliminary findings suggest that variability of CO\textsubscript{2} flow rates is substantial in all considered UK energy system scenarios. Variability is particularly high in low annual average emission intensity scenarios. Further, the baseline investigated CO\textsubscript{2} transportation pipeline networks are able to absorb flow rate variations nearly entirely when fluctuations happen on the basis of only a few hours (e.g. <4hrs). They will, however, not be able to absorb the majority of the fluctuations that are on the basis of cycles in the range of 8-12hrs. Additional balancing capacity in the form of e.g. tanks would need to be installed if fluctuations need to be fully absorbed by the transportation networks. Alternatively, if injection wells can cope with the residual flow variability, the usage of additional balancing capacity can be avoided.

References

