Flexible operation strategies for coal- and gas-CCS power stations under the UK and USA markets

Evgenia Mechleri\textsuperscript{a,b}, Paul S. Fennell\textsuperscript{c}, Niall Mac Dowell\textsuperscript{a,b}

\textsuperscript{a}Centre for Process Systems Engineering, Imperial College London, South Kensington, London SW7 2AZ UK  
\textsuperscript{b}Centre for Environmental Policy, Imperial College London, South Kensington, London SW7 1NA UK  
\textsuperscript{c}Department of Chemical Engineering, Imperial College London, South Kensington, UK

Abstract

The increased penetration of the intermittent renewable energy has increased the demand for flexible electricity supply. In this work, we evaluate four distinct strategies for flexible operation of CCS power plants: load following, solvent storage, exhaust gas by-pass and variable solvent regeneration (VSR) for coal- and gas-CCS power stations. With the aim to decoupling the power and capture plants in order to maximize profits, a multi-period dynamic optimisation problem was formulated and solved in the context of UK- and US-type markets. It was found that whilst the flexible operation strategies are strongly affected by the different markets, in all cases the variable solvent regeneration strategy was found to be the most profitable.

1. Introduction and scope

Carbon capture and storage (CCS) has been proposed as a means to enable a least-cost transition to a low carbon energy system and is also important for decarbonizing the industrial sector [1]. Given the increasing penetration of intermittent renewable electricity generation and the inflexible nature of traditional nuclear power generation, decarbonised power plants need to be designed for flexible operation in order to be able to promptly respond to variation in electricity demand [2] and to exploit the associated variation of electricity prices, while maintaining the carbon intensity of the plant at low levels [3]. Flexible capture can be achieved in a range of ways. At the level of an
individual power plant, flexible operation can be achieved using measures such as adding a solvent storage tank, bypassing the capture facility for certain time periods or operating the capture facility at different capture rates according to electricity output requirements (time varying solvent regeneration). To the best of our knowledge, the concept of flexible operation, was first introduced by Gibbins and Crane [4] in 2004, noting that this study makes reference to private communication with Prof Rochelle\(^1\) on this subject in 2002. In the 2004 study, the concepts of solvent storage and exhaust gas venting (or capture bypass) were first introduced. Subsequently, several contributions focused on flexible operation of the capture process as a way to improve the economics of CCS power plants either by reducing the capture level through exhaust gas venting, by storing the solvent using rich and lean amine storage tanks or by varying the degree of solvent regeneration [3, 5-12]. In the solvent storage strategy, two solvent storage tanks are added between the absorber and the stripper. If solvent storage is available then a portion of the rich solvent can temporarily be stored, rather than being sent to the desorber for immediate regeneration. This stored rich solvent can then be subsequently regenerated by adding it to rich solvent generated by ongoing operations during a period of relatively low electricity prices. Previously-stored lean solvent from another tank is used to allow capture to continue.

With the exhaust gas venting option, the power plant operates at times with partial or no capture of the CO\(_2\). Under this strategy, the energy required for solvent regeneration is anticipated to be reduced or eliminated by venting a portion of the exhaust gas directly to atmosphere. Thus, the steam that would have been used for solvent regeneration is instead not extracted, resulting in increased net power output. In the time varying solvent regeneration strategy, we use the working solvent as means to provide flexibility to the power plant. This is achieved by allowing CO\(_2\) to accumulate in the solvent during hours of peak electricity prices and regenerating the solvent during off-peak periods.

An important aspect that is analysed in this work is how the several flexible operation strategies differ in diverse markets. Traditionally, the main factors that affect the profits accrued by a power plant are the revenue from the increased power production during peak hours, the cost related to the carbon price and the fuel price. The increased deployment of intermittent renewable energy has two principle effects: to increase the volatility of electricity market and to reduce the important of fossil fuel prices in setting wholesale electricity prices. As has already been observed in Europe, a high penetration of intermittent renewable energy has the potential to produce negative electricity prices in addition to very high electricity prices [13]. Each year, long-term projections of the wholesale prices for oil, gas and coal for the UK under different strategies (low, central, high) are produced [14]. Carbon prices will also vary based on short-term traded carbon values for UK for central, low and high strategies. It is therefore essential to explore the profit sensitivity to these price oscillations. Moreover, it is interesting to examine the flexible operation strategies applied in different regions, UK vs USA, with high and low fuel prices, respectively and observe the profits of the decarbonised coal and gas power plants. In the remainder of this paper, using a load-following plant as the base case strategy, we apply a multi-period optimisation concept to compare three options for flexible operation of both coal- and gas-fired power plants: exhaust gas venting, solvent storage and time-varying solvent regeneration, under different electricity, carbon and fuel prices. We consider that the decarbonised power plants will be required to operate in a load following manner [3, 12, 15] as presented in Fig.1.
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