The effect of sorbent regeneration enthalpy on the performance of the novel Swing Adsorption Reactor Cluster (SARC) for post-combustion CO_2 capture

Schalk Cloete[1], Matteo C. Romano[2], Antonio Giuffrida[2], Abdelghafour Zaabout[1]*

1 SINTEF Materials and Chemistry, Trondheim, Norway

2 Politecnico di Milano, Department of Energy, Milan, Italy

**Corresponding author: abdelghafour.zaabout@sintef.no*

Highlights

- The SARC concept combines pressure swing with temperature swing using a heat pump.
- This allows SARC to efficiently utilize sorbents with a higher regeneration enthalpy.
- The effect of regeneration enthalpy on coal power plant efficiency is quantified.

1. Introduction

Regeneration heat duty is generally the most important factor influencing the energy penalty and cost of post-combustion CO_2 capture systems. For this reason, low regeneration enthalpy has long been the primary objective in CO_2 capture sorbent/solvent development.

The novel SARC concept [1] changes this narrative. This concept combines a vacuum swing using a vacuum pump and a temperature swing using a heat pump to regenerate the sorbent. A cluster of standalone bubbling fluidized bed reactors is used to accommodate the vacuum swing and enable processing of a steady incoming flue gas stream. Combining vacuum and temperature swings in this manner facilitates a small temperature difference between carbonation and regeneration (10-20 °C), thus allowing the heat pump to transfer the heat from carbonation to regeneration with a very high coefficient of performance ($COP \approx 0.7\,T_{cold}/\Delta T$).

In general, sorbents with a higher regeneration enthalpy are also more sensitive to temperature swing. This implies that a sorbent with a higher regeneration enthalpy will allow a smaller temperature swing to achieve a given sorbent utilization. Thus, even though such a sorbent will require more heat during regeneration; the smaller temperature swing will allow the heat pump to supply this heat more efficiently, creating an interesting trade-off for overall process efficiency.

This study will quantify the effect of sorbent regeneration enthalpy on the overall efficiency of a coal-fired power plant with post-combustion CO_2 capture using SARC.

2. Methods

Combined reactor and power plant modelling is employed to simulate the power plant efficiency. A detailed outline of the simulation setup can be viewed in our previous work [1].

The effect of sorbent regeneration enthalpy is investigated by simulating several hypothetical sorbents characterized by a Langmuir isotherm. Different regeneration enthalpies (dH in Equation 2) are employed to alter the temperature sensitivity of the resulting sorbent.

$$\frac{q}{q_{sat}} = \frac{b(T)p_{CO_2}}{1-b(T)p_{CO_2}} \qquad \textbf{Equation 1}$$

$$b(T) = b_0 \exp\left(\frac{dH}{RT}\right) \qquad \textbf{Equation 2}$$

An example of the difference in temperature sensitivity for sorbents with different regeneration enthalpies is given in Figure 1. Clearly, the sorbent with the higher regeneration enthalpy will enable a much smaller temperature swing, thus increasing the heat pump efficiency.

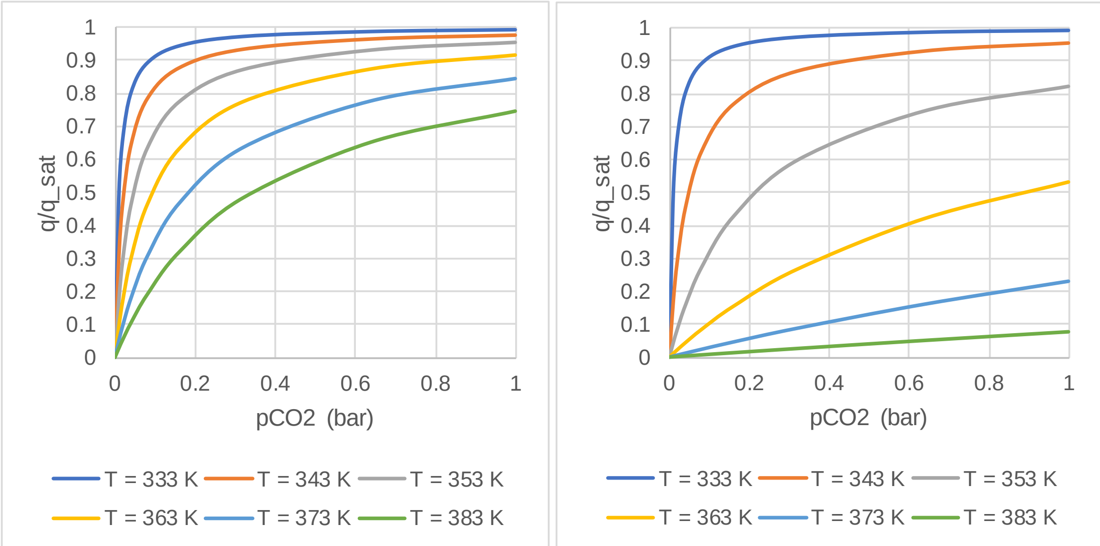

Figure 1. Isotherms for sorbents with a regeneration enthalpy of 75 kJ/mol (left) and 150 kJ/mol (right).

3. Results and discussion

A simplified initial analysis at a regeneration pressure of 0.1 bar has been completed to estimate the effect of regeneration enthalpy on the heat pump electricity consumption and the total heat transfer required. Figure 2 shows that higher regeneration enthalpies yield lower heat pump electricity consumptions. However, a larger total energy transfer is required as the larger reaction heat overwhelms the lower sensible heat transfer facilitated by the lower temperature swing, thus requiring a larger heat exchange surface inside the reactors.

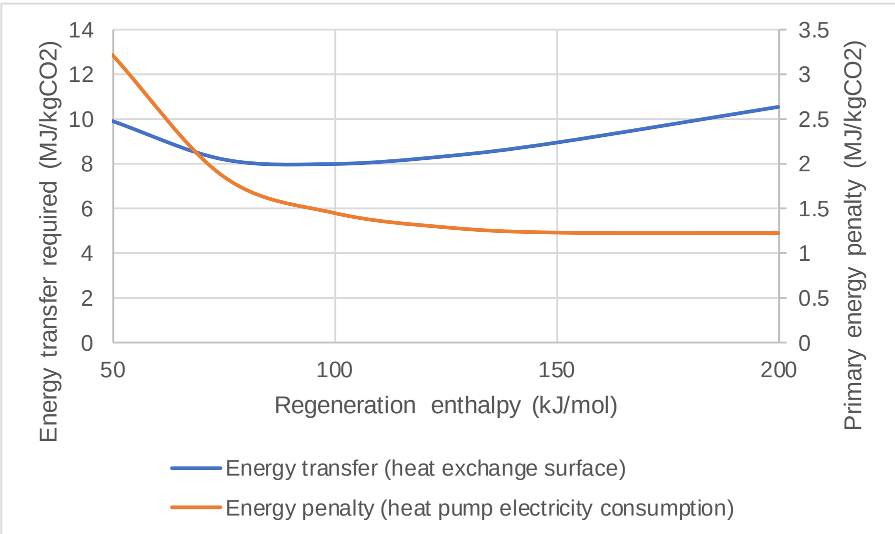

Figure 2. Preliminary estimate of the effect of regeneration enthalpy on system performance.

This simplified analysis therefore indicates an optimal sorbent regeneration enthalpy in the range of 100-150 kJ/mol where both heat pump electricity consumption and heat transfer surface area are close to a minimum. Rigorous combined reactor and power plant simulations will be completed to reproduce this primary result with a high degree of accuracy.

References

1. Zaabout, A., et al., International Journal of Greenhouse Gas Control, 2017. **60**(Supplement C): p. 74-92.