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Comparative analysis of thermodynamic theoretical models for energy consumption of CO_2 capture

Shuang-jun LI, Shuai DENG, Li ZHAO, Wei-cong XU, Xiang-zhou YUAN,
Yang-zhou ZHOU, Ya-wen LIANG

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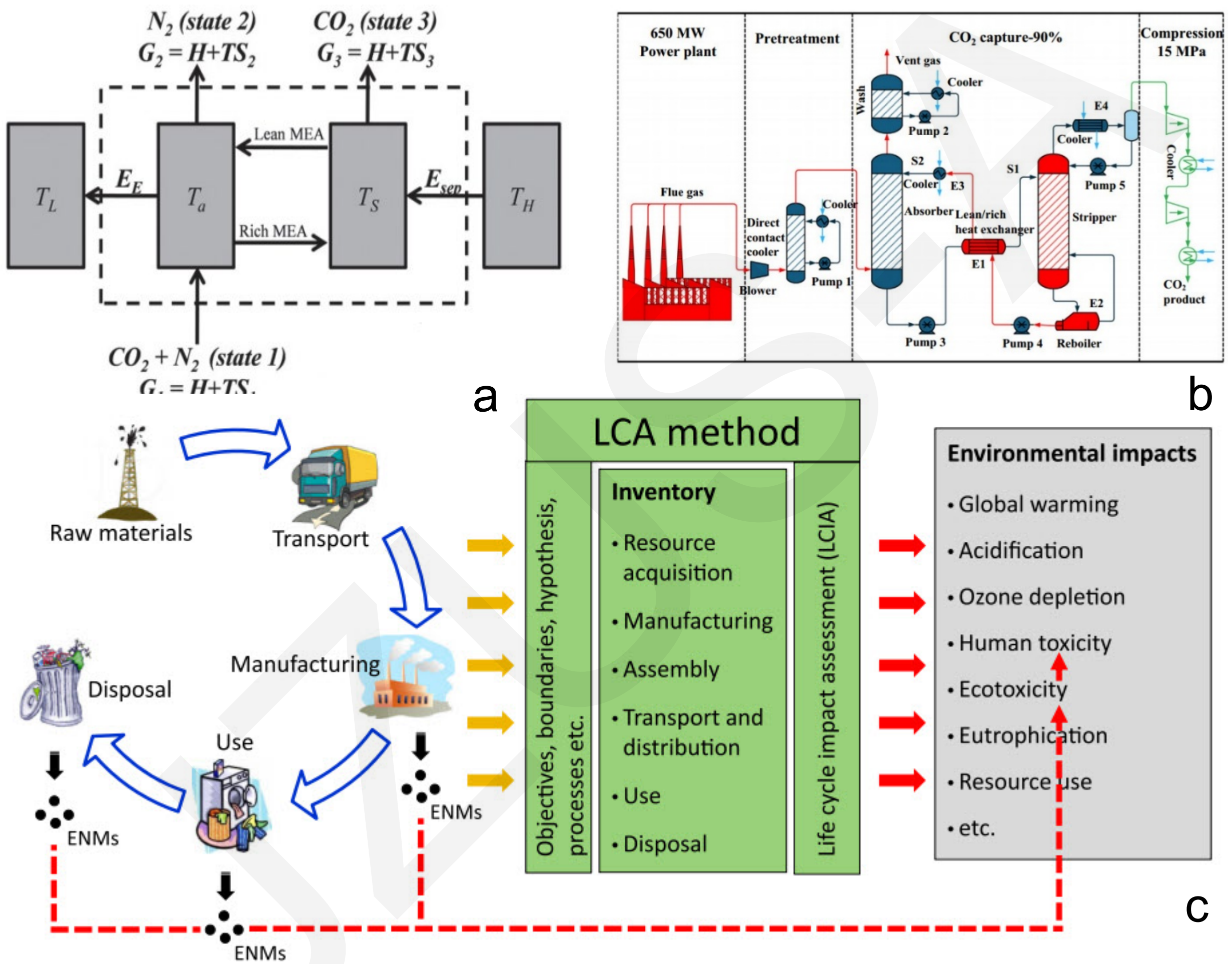
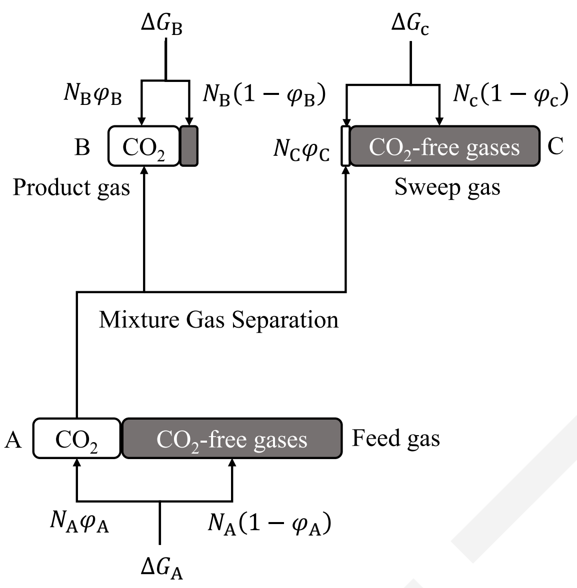
Background



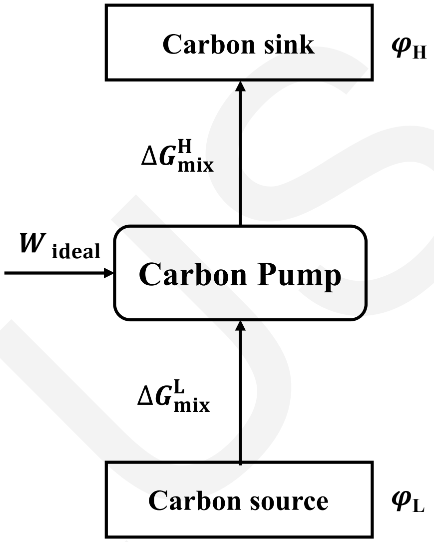
Sketch of traditional method for energy consumption evaluation of CO_2 capture technology :a. Mixture gas separation (MGS) model (House et al., 2009) b. Process engineering model (Zhao et al., 2017a) c. LCA model (Odeh and Cockerill, 2008)

Methodology

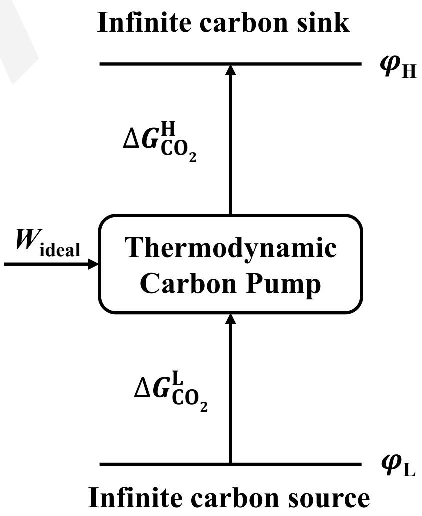
Thermodynamic study



Mixture gas separation (MGS) model



Carbon pump (CP) model



Thermodynamic carbon pump (TCP) model

Methodology

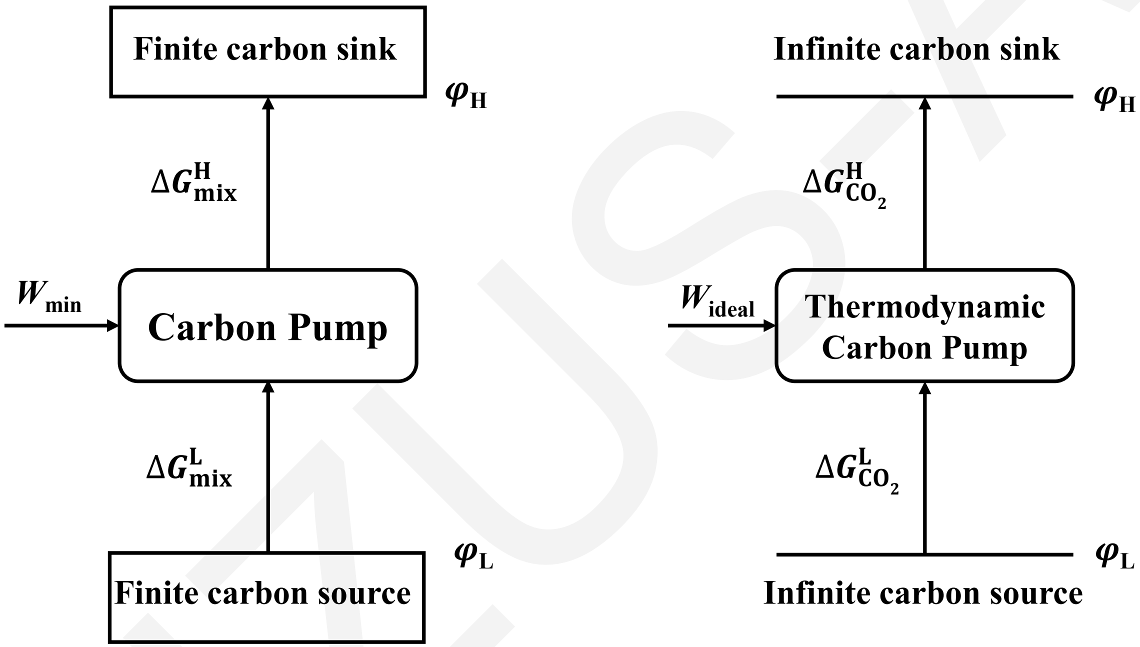
Carbon pump model

Feature	Heat pump	Carbon pump (CP)
Potential indicator	Temperature	Chemical potential
Source	Ambient air	Flue gas
Sink	Indoor air	Storage unit
Drive	Heat/power	Heat/power
Function	Heat transfer	CO_2 concentration
Direction	Source → Sink	Source → Sink
Typical technology	Vapor-compression, absorption	Absorption, adsorption

- The carbon pump (CP) model proposed by Zhao et al. (2017b) was focused primarily on the energy-efficiency of different CO_2 capture technologies.

Methodology

■ Thermodynamic carbon pump (TCP) model

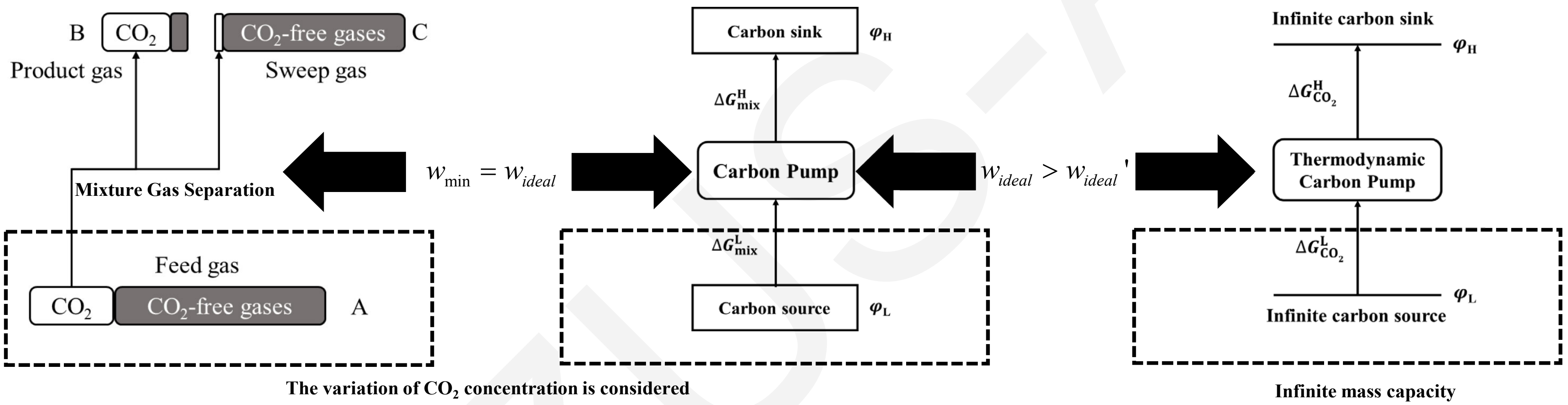


$$w_{ideal}{}' = \left(\Delta G^{H}_{CO_2} - \Delta G^{L}_{CO_2}\right) \Big/ N_{H,CO_2} = RT\ln\left(\frac{\varphi_H}{\varphi_L}\right),$$

- The carbon source and sink are treated as with infinite mass capacity in the TCP model

Comparison results

■ Comparison between MGS, CP and TCP



- Compared to the MGS model, the CP model is more suitable for evaluation of practical engineering
- Due to the assumption of mass conservation, the MGS model cannot be expanded to a more ideal physical scenario, but a CP model can be expanded to a TCP model in which carbon sources or sinks have approximately infinite capacity.

Conclusion

1. The correctness and convenience of the CP model were indicated by comparison with the MGS model. The ideal energy consumption w_{ideal} calculated by the CP model was proved to be correct, and the convenience of such a model applied in a practical project was also proved.
2. Calculations from the TCP model more closely approached the ideal status than those from the CP model. The ideal minimum energy consumption w_{ideal}' calculated by the TCP model followed the same variation trend as the ideal energy consumption wideal calculated by the CP model, and the w_{ideal}' proved to be smaller. The irreversibility in the CP model caused by the variation of the CO_2 concentration in the carbon source and sink occurred in an actual situation, such as in flue gas scrubbing technology.
3. The minimum ideal energy consumption of DAC was evaluated with the application of the TCP model and turned out to be 4.916 times that of flue gas scrubbing in the same conditions (except for the CO_2 concentration in the feed gas). The w_{ideal}' of DAC measured in the TCP model was 19.334 kJ/mol of CO_2, when the CO_2 concentration in the air was assumed to be 400 ppm, and the CO_2 concentration of the product gas was set as 98% at an ambient temperature of 298 K and pressure of 1 atm.