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Techno-economic study of CO2 capture & compression unit incorporating a high temperature heat pump system

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Abstract

1. Introduction

Amine scrubbing is widely used in commercial plants that capture CO2 from exhaust gases. However, considerable amount of heat energy is required to regenerate the solvent, and much of this heat is wasted because cooling is necessary at various points in the process. The use of a heat pump system is an attractive option to improve the thermal efficiency of the entire process and is investigated as one of the solutions to these problems [1),2)].

Turboden and MHI has been carrying out an integration study of the CO2 capture process with a heat pump. MHI's presentation at PCCC7 in 2023 reported the results of a study assuming a waste heat source inside a CO2 capture plant.

This presentation focuses on the study result to achieve a high COP (coefficient of performance) for the heat pump utilizing waste heat from both CO2 capture plant and CO2 compressor. The CO2 capture system envisages MHI's proprietary technology, the advanced KM CDR Process™.

2. Heat Pump System Application to advanced KM CDR Process™

A large portion of the OPEX of the CO2 capture process consists of the reboiler heat and the cooling duty of various process parts. The transfer of low-temperature waste heat to the high-temperature reboiler by the heat pump can reduce or even eliminate the amount of heat to be supplied from outside. A high temperature heat pump working with a natural refrigerant was selected for integration with the CO2 capture process in this study. The following waste heat sources are considered as:

1) Quenching of hot flue gas before CO2 absorption
2) Separation of CO2 and water vapor by cooling at the top of the regenerator
3) Cooling at the top of the absorber to handle the exothermic CO2 absorption reaction
4) Intercoolers of CO2 compressor

The heat pump is designed to transport the above waste heat sources to the reboiler. The refrigerant is compressed, and heat is given to the reboiler. It then undergoes isenthalpic expansion and its temperature decreases. It then receives heat from the heat source.

3. Techno-Economic Assessment

3.1 Study condition

The study assumes a typical European project as shown in Table 3.1.

Table 3.1 Techno-economic assessment condition

Operation condition		EPC cost	
Flue gas flow rate (Nm^3/hour)	309,201	Availability (%)	0.04
CO2 capacity (tonne/day)	1,700	Redundancy (%)	14.0
CO2 concentration (vol.%)	13.0	Capital charge factor (1/year)	0.124
H2O concentration (vol.%)	33.8, Adjusted	CO2 emission correction for electricity (kg-CO2/kWh)	0.207
Utility cost			
Electricity ($/kWh)	0.04		
Steam ($/tonne)	14.0		
Cooling water makeup ($/$m^3$)	0.2		

3.2 CAPEX & OPEX

Capital expenditures (CAPEX) and operating expenditures (OPEX) are studied with and without heat pumps for the CO2 capture unit including cooling water and boiler systems. CAPEX increases with installing the heat pump, but it can reduce the utility unit cost. Steam supply is not required if the duty of the waste heat is high enough. The normalized annualized CO2 cost, which is the sum of CAPEX and OPEX, is cheaper with the heat pump than without the heat pump if CO2 capacity takes into account CO2 emissions from utilities such as boilers.

4. Conclusion

The study result shows that the usage of waste heat for regeneration heat in the amine CO2 capture by the heat pump can lead to reductions in not only OPEX but also total CO2 cost if utility units are evaluated in addition to the CO_2 units. This is because the increase in CAPEX due to the adoption of heat pumps can be offset by reduced utility equipment costs for steam and cooling water. The waste heat from the CO2 compressor can be effectively utilized when the flue gas has low moisture and/or low temperature, even though its duty is relatively small.

References

[1] Ebbe Hauge Jensen, “Electrification of amine-based CO2 capture utilizing heat pumps”, Carbon Capture Science & Technology, volume 10, March 2024, 100154

[2] Zhiwei Zhang, Enhancing energy efficiency of chemical absorption-based CO2 capture process with advanced waste-heat recovery modules at a high capture rate, Chemical Engineering Journal, volume 472, 15 September

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