Lean Vapor Compression in a carbon capture plant: an economic evaluation

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1. Introduction

Energy optimization is crucial for the lowering of operational cost for post combustion capture. Next to solvent optimization, process optimization is of equal importance. An interesting option is the use of lean vapor compression (LVC). This comprises flashing of the bottom stream of a stripper and recycling the resulting vapor after compression to the bottom stage of the stripper. LVC has proven to be technically feasible in the European project CESAR. In this study a detailed economic assessment for the capital and operational expenditure is made for a demo-scale MEA capture plant of 180 ton CO_2 per hour.

2. Approach

A standard CO_2 capture plant based on 30wt% MEA was modelled in Aspen Plus. This model was verified based on the comparison with experimental data form the Esbjerg pilot plant. This modelled process was scaled up to a 180 ton/hr capture plant, which was connected to a coal-fired power plant. Two cases were considered:

1. Design of the capture plant with LVC to arrive at minimal investment cost.
2. Using LVC as an add-on to an already designed capture plant.

At the process settings listed in Table 1, the pressure in the LVC flash vessel was varied from 1 to 1.8 bara.

Table 1: Settings used in MEA capture process.

Capture percentage [%]	90	Flue gas data	
MEA concentration [wt%]	30	CO_2 [mol%]	0.144
Stripper pressure (drop) [bara]	1.8 (0.1)	H_2O [mol%]	0.074
CO_2 recovery to stripper bottom	0.57	T/P [°C]/[bara]	40 / 1.1
T lean absorber feed [°C]	40	Flow [kg/s]	254

For each pressure, the net present value of the gain and cost of LVC were calculated using the parameters in Table 2. The following gains/costs were considered:

- Energy cost: by application of LVC, the energy requirement for boil-up in the stripper is divided between the reboiler and the LVC compressor. In order to add the electrical energy to the thermal energy, the electrical energy was divided by 0.25. This is the reduction in power-output of the power plant per megawatt of reboiler energy generally seen in carbon capture calculations.

- Equipment cost: quotes were made for the main equipment of the capture process. In order to calculate equipment prices for each LVC case the quotes were scaled using the appropriate price functions for each piece of equipment.

Table 2: Parameters used to calculate the NPV of the yearly costs and gains.

Interest percentage	8%	**Depreciation**	**Years**
Lang factor	4	Compressor	10 (lowered for maintenance)
Electricity [€/MWh]	50	Flash vessel	25 (nominal value)
Time period (years)	25	Heat exchangers	20 (lowered for maintenance)

3. Results

The calculated thermal duties and the difference in equipment cost compared to a plant without LVC are listed in Table 3. The operational and capital cost of the reboiler, condenser, LVC compressor, and LVC flash have been calculated. The rest of the equipment is assumed not to be significantly affected by the LVC (this assumption was checked for an optimal case). For case 2, only the cost of the LVC compressor and flash are considered, as they are the add-on to the existing process.

As the pressure in the LVC flash vessel lowers, more vapor is formed and, with the vapor, more heat is pumped into the stripper bottom by LVC, hence the reboiler duty lowers. It can be seen that the electric duty of the LVC compressor rises exponentially with lowering flash pressure. In case 1 the cost of the lean-rich heat exchanger and the condenser lower with decreasing flash pressure. This results in over-all lower investment cost for case 1. This is offset by the slightly higher energy gain in case 2.

The NPV of the yearly gains and cost over 25 year is given in Table 3. This shows that for both cases the highest benefit of LVC can be attained at a flash pressure of ~1.2 bara. Moreover, the gain over 25 years is the same for both cases. Case 2 will yield the highest plant flexibility and is, therefore, the most favorable option.

Table 3: resulting duties and equipment cost for case 1 and 2. Left box: case 1, right box: case 2.

P_{LVC} bara	boil-up duty MWth	Equipment installed M€	NPV energy savings M€	NPV cost savings M€		boil-up duty MWth	Equipment installed M€	NPV energy savings M€	NPV cost savings M€
1.8	172	0	0	0		172	0	0	0
1.4	162	-0.8	11.2	11.2		161	1.8	12.3	10.8
1.2	159	0.8	14.7	13.0		157	3.8	16.3	13.0
1	157	3.43	16.0	11.3		155	7.5	18.8	12.0

It can be concluded that LVC is an interesting option for lowering the cost of post combustion capture, reducing the energy demand of the MEA process with some 8%. It is to be expected that LVC will lead to improvement for other solvent systems. However, the extent of the savings needs to be evaluated case by case.